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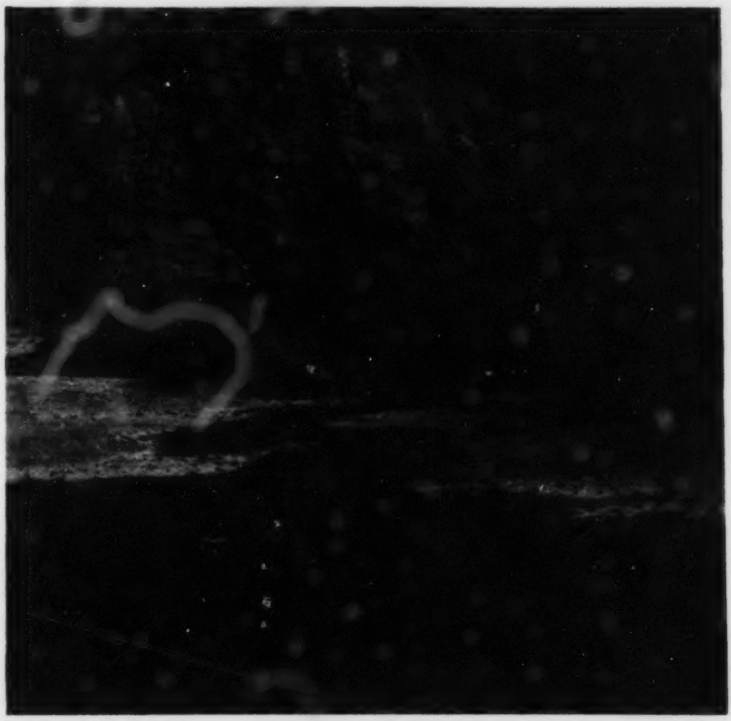
LITHOLOGIC FACIES, SEISMIC FACIES, AND STRIKE-SLIP SETTING OF THE LOWER CARBONIFEROUS ALLUVIAL/FLUVIAL/LACUSTRINE ALBERT FORMATION OF NEW BRUNSWICK

C. St. Peter



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Cover Photo:
Modern analog of interpreted Albert Formation depositional environments. In background steep fault scarp with adjoining steeply inclined talus breccia fans changes down slope to medial and distal alluvial fan deposits. The medial fan sediments (behind packsack) are dominantly sand; the distal fan deposits are largely desiccated muds. Fluvial-deltaic environments are shown by the stream which crosses the mudflat and discharges into the "lake". Gradual transitions from subaerial mudflats to shallow lacustrine to deeper lacustrine environments are displayed in the foreground.

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ABSTRACT

The Lower Carboniferous (Tournaisian) oil- and gas-bearing Albert Formation of southeastern New Brunswick occurs within the Moncton Subbasin, which is a substructure of the larger Late Paleozoic Maritimes Basin. The subbasin is about 30 km wide and 150 km long; it lies upon Precambrian and Lower Paleozoic deformed crystalline rocks of the Avalon terrane. The sedimentary fill is mainly terrestrial, and is 5-6 km thick in the axial part of the subbasin. The fill comprises 3 depositional sequences separated by two basin-wide unconformities. The oldest depositional sequence is the 3-5 km thick Horton Group, comprising three conformable formations: basal Memramcook, medial Albert, and upper Weldon.The Albert Formation is divided into six lithofacies: (1) basin margin proximal alluvial fan and fan-delta conglomerates, (2) transgressive/regressive shallow lacustrine sandflats, (3) interstratified marginal lacustrine mudstones and sandstones, (4) subaerial mudflats, (5) deep lacustrine organic matter-rich mudstones and oil shales, and (6) perennial and ephemeral (playa) saline lake evaporites.

Four seismic facies based on characteristic reflections are recognized in the Albert Formation. The seismic facies are correlated with surface data and well logs to enhance the geometrical interpretation of subsurface lithofacies.

Geologic evidence and seismic reflection profiles indicate that during early Horton time the Moncton Subbasin evolved via a three-part strike-slip cycle. The subbasin was apparently initiated by transtension in Late Devonian time. From then through most of the Tournaisian the subbasin subsided along oblique dip-slip marginal faults with resultant transverse-to-basin coarse alluvial fans, fan-deltas, and deltaic sedimentation. The northeast-trending axial part of the subbasin is dominated by fine-grained fluvial and lacustrine deposits with longitudinally directed paleoflows. The strike-slip cycle ended with a dextral transpressive event evidenced by northeast- trending anastomosing wrench faults, en échelon folds, duplex and positive flower structures, uplifts and an erosional unconformity. The Albert Formation was subsequently deformed by later Carboniferous and possibly Mesozoic faulting events. Albert lithofacies and seismic facies interpretations suggest that there are promising and yet untested oil and natural gas prospects on the same trend as the historically productive Stoney Creek Gas and Oil Field.

RÉSUMÉ

La formation pétrolifère et gazéifère du Carbonifère inférieur (Tournaisien) d'Albert dans le sud-est du Nouveau-Brunswick se présente au sein du bassin secondaire de Moncton, qui constitue une structure secondaire du bassin des Maritimes plus étendu du Paléozoïque supérieur. Le bassin secondaire a environ 30 km de largeur sur 150 km de longueur. Il repose sur des roches cristallines déformées du Précambrien et du Paléozoïque inférieur du terrane d'Avalon. Le remplissage sédimentaire est essentiellement terrestre, et il présente une épaisseur de cinq à six kilomètres dans la partie axiale du bassin secondaire. Le remplissage comporte trois paragénèses sédimentaires séparées par deux discordances à l'échelle du bassin. La paragénèse sédimentaire la plus ancienne est constituée du groupe Horton, d'une épaisseur de trois à cinq kilomètres, comprenant trois formations concordantes : la formation basale de Memramcook, la formation médiane d'Albert et la formation encaissante de Weldon. La formation d'Albert est divisée en six lithofaciès : (1) les conglomérés de cônes alluviaux et de cônes de déjections marginaux proximaux du bassin; (2) les platins de sable lacustres peu profonds transgressifs et régressifs; (3) les grès et les limons compacts lacustres marginaux interstratifiés; (4) les limons compacts subaériens; (5) les schistes bitumineux et le limons compacts profonds riches en matières organiques lacustres; et (6) les évaporites permanents et éphémères de lac salé (temporaire).

On reconnaît quatre séismofaciès basés sur des réflexions caractéristiques dans la formation d'Albert. Les séismofaciès sont interreliées par des données superficielles et des diagraphies de puits pour faciliter l'interprétation géométrique des lithofaciès internes.

Les données géologiques et les profils de réflexion sismique révèlent qu'à l'époque du Horton supérieur, le bassin secondaire de Moncton a évolué selon un cycle de coulissage en trois phases. Le basin secondaire a apparemment été instauré par une transtension survenue au cours du Dévonien supérieur. Dès lors, pendant une bonne partie du Tournaisien, le bassin secondaire s'est affaissé le long des failles marginales à rejet oblique produisant des cônes alluviaux grossiers, des cônes de déjections et une sédimentation deltaïque, transversaux au bassin. La partie axiale orientée vers le nord-est du bassin secondaire est dominée par des dépôts fluviatiles et lacustres à grains fins, ainsi que par des écoulements paléolithiques orientés longitudinalement. Le cycle de coulissage a pris fin avec l'activité transgressive dextre comme le prouvent les réjeux décrochants anastomosés, les plis en échelons, les structures florales doubles et positives, les soulèvements et la discordance d'érosion. La formation d'Albert a été subséquemment déformée par le Carbonifère supérieur et, possiblement, par des dislocations secondaires. L'interprétation des lithofaciès et des séismofaciès d'Albert laisse supposer l'existence de sites pétrolifères et gazéifères intéressants et prometteurs, quoique non vérifiés, selon la même tendance que le champ gazéifère et pétrolifère de Stoney Creek qui a déjà été productif.

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INTRODUCTION

GENERAL STATEMENT

During the energy crisis of the early nineteen-eighties the New Brunswick Department of Natural Resources and Energy embarked on a program to evaluate the oil shale resources of the Albert Formation. As a result, the author was assigned responsibility to undertake a geological lithofacies study of the Albert strata in the Moncton Subbasin of southeastern New Brunswick. Most rock exposures of the Albert were examined from 1982 through 1984; additional field work was carried out during the summers of 1989 and 1990.[1] Fourteen preliminary maps from this work are available at 1:20 000 scale from the Department of Natural Resources and Energy (St. Peter, 1989).

Geological field studies in New Brunswick are in general hampered by limited rock exposures. This is especially true in areas underlain by Carboniferous rocks where shales and mudstones are soft and crumbly and sandstones are commonly poorly cemented and friable. In addition to the problem of rock exposure, the Albert Formation, being a terrestrial sequence, is characterized by rapid facies changes (Greiner, 1962; Carter, 1985; Carter and Pickerill, 1985a). If this were not enough, the formation is cut by a multitude of steeply dipping brittle faults, the sense(s) and magnitudes of displacement of which are poorly known but often debated (Gussow, 1953; Webb, 1963, 1969; Belt, 1968; Ruitenberg and McCutcheon, 1982; Leger, 1986; Leger and Williams, 1986). As a consequence of these problems, the lithofacies assessment undertaken on the Albert strata has been considerably handicapped.

In January 1989, 1 900 km of Vibroseis seismic reflection profiles shot from 1981 to 1984 by Chevron Canada Resources Limited in the Moncton and Sackville subbasins became publicly available (Three-D Geoconsultants Limited, 1990). Following the release of this data, it was decided that the reflection profiles should be examined in an attempt to overcome some of the problems that beset the geological field studies. This report is an account of: (1) the results of the geological investigations on the Albert Formation in the southeastern Moncton Subbasin, and (2) the integration of interpreted seismic reflection profiles to help resolve some of the geological problems encountered. The report is reproduced in its entirety, with only format changes, from St. Peter's (1992) M. Sc. thesis.

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[1] See Appendix 1 (page 133) for location of all Albert Formation outcrops visited.

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PURPOSE

The purposes of this report are: (1) to describe the sedimentary facies of the Lower Carboniferous terrestrial Albert Formation in the southeastern Moncton Subbasin of New Brunswick, (2) to describe the seismic stratigraphy and seismic facies of the Albert Formation as seen from migrated seismic reflection profiles, (3) to assess from field observations and seismic profiles the possible mechanism of inception of the Moncton Subbasin, (4) to elucidate the main elements of basin dynamics, and (5) to suggest from the above analyses potential new prospective areas for mineralization, and for oil shale and oil and natural gas exploration.

SUMMARY OF REGIONAL GEOLOGIC HISTORY

The Albert Formation is an Early Carboniferous (Varma, 1969; Pickerill, *et al.*, 1985; Utting, 1987a) section of predominantly clastic terrestrial strata deposited in the Moncton Subbasin of southeastern New Brunswick. The Moncton Subbasin is one of several subbasins comprising the larger Maritimes Basin (Roliff, 1962; Kelley, 1967; Williams, 1974; Howie and Barss, 1974, 1975). To appreciate the sedimentologic and tectonic evolution of the Albert Formation an understanding is required of the controlling influence of faults in the complex basement terranes underlying the basin, and of the regional geology of the rocks comprising the Late Paleozoic Maritimes Basin.

Precambrian to Middle Devonian Basement Complex

The Late Devonian to Permian rocks of the Maritimes Basin (Figure 1) unconformably overlie a complex collage of basement terranes that comprise the northeastern end of the Appalachian orogen (Roliff, 1962; Bird and Dewey, 1970; Williams, 1974; Williams, 1979; Williams and Hatcher, 1982; Bradley, 1982; Ruitenberg and McCutcheon, 1982; Haszeldine, 1984; Keppie, 1985; Rast, 1984, 1989; Stockmal, *et al.*, 1987; Marillier, *et al.*, 1989). The basement rocks range in age from Proterozoic Grenville gneiss to Middle Devonian plutonics, volcanics, and sedimentary rocks.

In the past twenty-five years several summary accounts of the geology and plate tectonic evolution of the northeastern Appalachian chain have been published (Wilson,

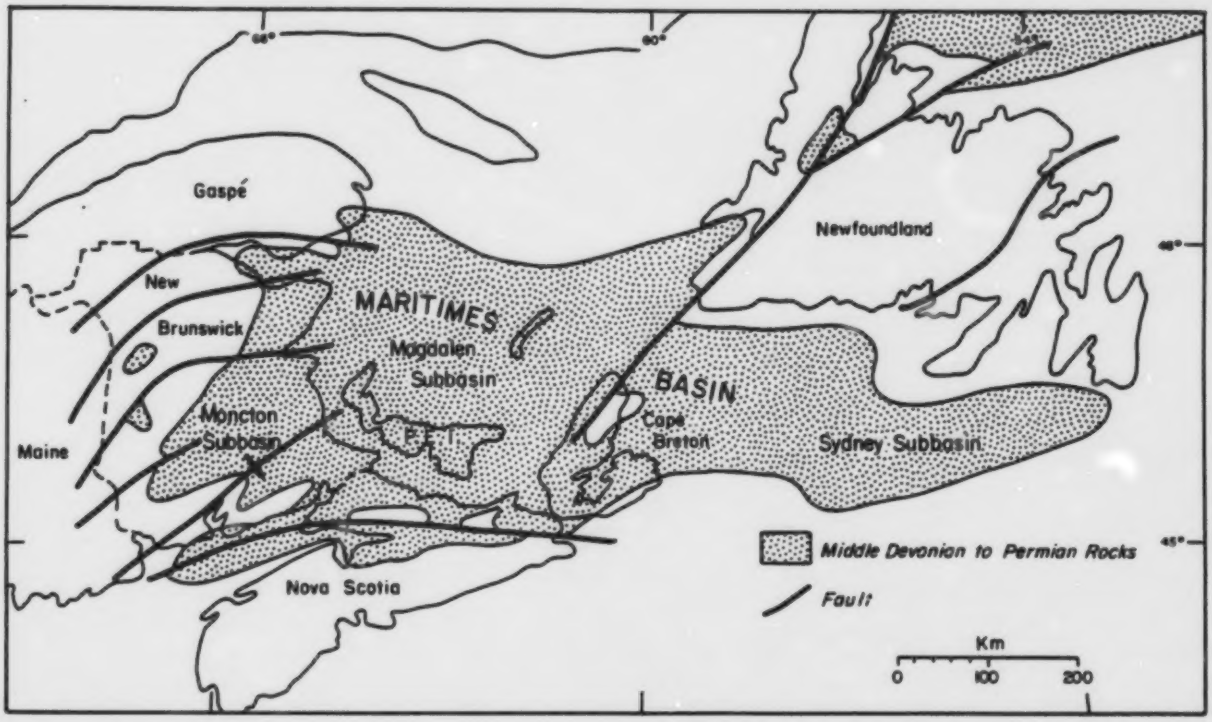
66°
60°
Gaspé
Newfoundland
48°
New
Brunswick
MARITIMES
BASIN
Magdalen
Subbasin
Moncton
Subbasin
P.E.I.
Cape
Breton
Sydney Subbasin
Maine
Nova Scotia
45°
Middle Devonian to Permian Rocks
Fault
Km
0
100
200

Figure 1: Maritimes Basin showing the present erosional edge of mainly the Upper Carboniferous/Permian late sag phase of the basin (cf. Figure 3). Taken from Roliff (1962), Williams (1974), Bradley (1982), and Fyffe and Barr (1986).

1966; Poole, 1967; Bird and Dewey, 1970; Williams, 1979; Williams and Hatcher, 1982; Rast, 1984, 1989; Stockmal, *et al.*, 1987; Williams, 1988; Barr and Raeside, 1989; Marillier, *et al.*, 1989). The descriptive account and model which has gained widest acceptance is that of Williams (1978 ,1979), and the later revision of this by Williams and Hatcher (1982). They divided the Ordovician and older basement rocks of the northeastern Appalachians into five tectonostratigraphic zones (Figure 2). From northwest to southeast the zones are: Humber, Dunnage, Gander, Avalon, and Meguma.

The Humber represents the ancient continental margin of eastern North America. It comprises Proterozoic Grenville basement overlain by a miogeoclinal sequence of Cambro-Ordovician clastics, carbonates, and local volcanics that are believed to represent the passive northwestern margin of the Iapetus Ocean. The southeastern margin of the Iapetus Ocean in the northeastern Appalachians is defined by the Gander zone (Williams, 1978, 1979). The Gander rocks are mainly metamorphosed and polydeformed pre-Middle Ordovician arenaceous strata such as the lower Tetagouche Group of New Brunswick (Williams, 1979; Barr and Raeside, 1989). Paleozoic megacrystic granites, leucogranites, and pegmatites are common in the Gander terrane.

The Dunnage zone lies between and allochthonously upon the Humber and the Gander in Newfoundland (Williams, *et al.*, 1988). The Humber and Dunnage are in tectonic contact along the Long Range Fault and Baie Verte Line in Newfoundland (Figure 2). In the southeast,

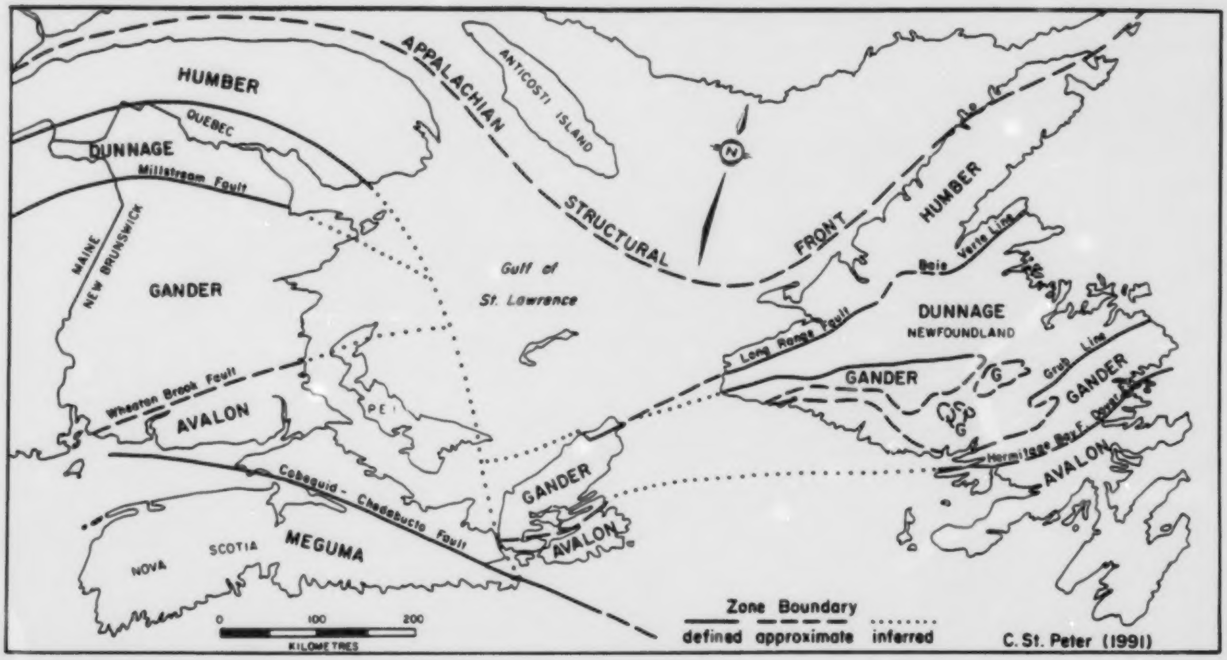
HUMBER
QUEBEC
DUNNAGE
Millstream Fault
MAINE
NEW BRUNSWICK
GANDER
Wheaton Brook Fault
AVALON
PEI
Cobequid - Chedabucto Fault
MEGUMA
NOVA SCOTIA
APPALACHIAN STRUCTURAL FRONT
ANTICOSTI ISLAND
N
Gulf of St. Lawrence
HUMBER
Baie Verte Line
DUNNAGE
NEWFOUNDLAND
Long Range Fault
GANDER
G
G
GRUB Line
GANDER
Dover F.
Hermitage Bay F.
AVALON
GANDER
AVALON
0 100 200
KILOMETRES
Zone Boundary
defined approximate inferred
C. St. Peter (1991)

Figure 2: Tectonostratigraphic zones of northern Appalachians; G = Gander Zone "inliers" in Newfoundland. Compiled after Williams (1979), Williams and Hatcher (1982), McCutcheon (1981), McCutcheon and Robinson (1987), Williams, *et al.* (1988), Barr and Raeside (1989), Marillier, *et al.* (1989), Durling and Marillier (1990), and St. Peter and Fyffe (1990).

"inliers" of Gander are seen through structural windows of the Dunnage (Williams, *et al.*, 1988). There are no Dunnage rocks on Cape Breton Island (Barr and Raeside, 1989). The Dunnage is an oceanic terrane as evidenced by abundant ophiolites, mafic volcanics and associated marine sediments; for example, in northern New Brunswick the Dunnage includes the Fournier Complex ophiolites and covering volcanics (Williams, 1979; Rast and Stringer, 1980; Flagler, 1989). The volcanics and volcaniclastics that overlie the ophiolites are interpreted as an island arc sequence.

In Newfoundland the Gander is in contact to the southeast with the Avalon zone along the Dover and Hermitage Bay faults (Figure 2). In Cape Breton the contact between the Avalon and Gander zones is not yet firmly established; for example, compare the conflicting interpretations in Rast (1989), Barr and Raeside (1989), and Marillier, *et al.* (1989). Likewise, the Gander/Avalon boundary is not yet resolved in New Brunswick (St. Peter and Fyffe, 1990). It may be at the Wheaton Brook Fault (McCutcheon, 1981b), or the Fredericton Fault (Stockmal, *et al.* 1987), or the Belleisle Fault (Rast and Stringer, 1974; Nance, 1987).

Williams and Hatcher (1982) interpreted the Avalon zone as a suspect terrane; Rast (1989) believes it is a collage of blocks which he designates a superterrane. The preponderance of evidence suggests the Avalon accreted to North America (i.e., the Gander zone) in the mid-Paleozoic along a steep transcurrent suture (Marillier, *et al.*, 1989). In New Brunswick the Avalon zone defines the basement of the Moncton Subbasin (cf. Figures 2 and 3). A summary of the geology and plate tectonic evolution of the

Avalon zone in New Brunswick has been given by Nance (1987), Bevier and Barr (1990), Bevier, *et al.* (1990), Barr and White (1991), and Fyffe, *et al.* (1991). Barr and White (1991) have accordingly divided the Avalon zone into two northeast-trending belts separated by a major fault zone. The more northern belt, or Brookville terrane, comprises 900 Ma(?) platformal marbles, quartzites, phyllites, and conglomerates of the Green Head Group and younger paragneises (641 Ma) and orthogneiss (605 Ma) of the Brookville Gneiss complex. The Brookville terrane is largely concealed and forms the floor of the Moncton Subbasin. The more southern belt, or Caledonia terrane, comprises late Precambrian and Eocambrian turbidites, terrestrial sedimentary rocks, and marine and subaerial bimodal volcanics of the Coldbrook Group. The Coldbrook Group is in part a marine volcanic arc sequence (Rast, *et al.*, 1976; Giles and Ruitenberg, 1977; McLeod, 1986; Bevier and Barr, 1990; and Fyffe, *et al.*, 1991), and in part a subaerial rift assemblage (Ruitenberg and Giles, 1977; McLeod, 1986; and Barr and White, 1988, 1991). The Brookville and Caledonia terranes are intruded by distinctly different plutonic suites (Barr and White, 1991).

Coldbrook Group rocks of the Caledonia Uplift (Ruitenberg, *et al.*, 1979), define the southern margin of the Moncton Subbasin (Plate 92-33). The Coldbrook Group and older Brookville terrane rocks are unconformably overlain by mildly deformed Eocambrian redbeds and volcanics, and Cambro-Ordovician Saint John Group conglomerates, sandstones, and shales (Tanoli, 1987), the latter representing the southern margin of the Iapetus platform (Nance, 1986a, 1987).

The Avalon of New Brunswick is characterized by numerous northeast-trending steeply dipping transcurrent faults (Leger, 1986; Leger and Williams, 1986). Ductile dextral movements on the faults have been assigned a Precambrian age by Nance (1987), and an Acadian (Devonian) age by Leger and Williams (1986) and Leger, *et al.*, (1988). Regardless of the timing of early ductile displacements, Late Devonian and Carboniferous brittle dextral displacements on the faults controlled the inception(?) and inversion of the Moncton Subbasin (see pages 86-93).

The Meguma is the most southeastern tectonostratigraphic zone in the northeastern Appalachians (Figure 2). It is separated from the Avalon zone along the east-west-trending Cobequid-Chedabucto Fault in northeastern Nova Scotia. The Meguma zone, or terrane of Williams and Hatcher (1982), comprises a generally shallowing-upward sequence up to 23 km thick of Upper Cambrian to Lower Devonian deep water to inner shelf arenites, wackes and lesser grey slates. Within the Meguma section there are five black slate intervals that are interpreted as muds deposited under anoxic conditions during periods of sea level high-stand (Schenk, 1991). The marine clastics are interrupted by three unconformities. Each unconformity is located at the base of a relatively thin subaerial to submarine volcanic interval. The paucity of macrofauna or microfauna prohibits a clear indication of the amount of section missing or the time interval represented by the lower two (i.e., Ordovician and Silurian) unconformities (Schenk, 1991, fig. 2). The Meguma terrane is intruded by Devonian granitoid batholiths.

The Carboniferous strata of the Maritimes Basin are the first overlap assemblage linking the Meguma with the Avalon, implying the Meguma docked with North America in the Late Paleozoic (Williams and Hatcher, 1982). The suture zone between the two terranes, the Cobequid-Chedabucto Fault, is a steeply dipping dextral transcurrent structure in Nova Scotia (Eisbacher, 1969). The fault is linked with an imbricate thrust front along the north side of the Bay of Fundy in New Brunswick (Rast, 1984; Mosher and Rast, 1984; Ruitenberg and McCutcheon, 1982; Nance and Warner, 1986). Movement on the Meguma-Avalon boundary fault zone during the Late Carboniferous (Alleghenian orogeny) is reflected by transpressive displacements cutting the Moncton Subbasin sequences. Chevron Canada Resources seismic reflection lines in the Bay of Fundy demonstrate that transpression continued on the Cobequid-Chedabucto Fault until at least the Early Jurassic.

Upper Paleozoic Maritimes Basin

The Maritimes Basin (Figure 1) is the largest intermontane basin in the Appalachian Mountain system (Williams, 1974). It has an area of 148 000 km^2 of which about 70 per cent is offshore in the Gulf of St. Lawrence and beneath the continental shelf. The Maritimes Basin was named by Roliff (1962); it comprises those predominantly terrestrial strata deposited after the Acadian orogeny in late Middle Devonian to Early Permian time, with angular unconformity on the deformed tectonostratigraphic zones or the terranes described above.

A comprehensive up-to-date synthesis of the geology and tectonic evolution of the Maritimes Basin is not available, but is badly needed. Much work has been undertaken in the past decade by many geologists. Some of the relevant regional studies include those of Fralick and Schenk (1981), Bradley (1982), Knight (1983), Gibling and Rust (1986), McCutcheon and Robinson (1987), St. Peter (1987a), Yeo and Ruixing(*sic*) (1986), Boehner, *et al.* (1986), and Hamblin (1989).

A generalized summary of the Maritimes Basin has been given by Bradley (1982). He describes the basin as a two-part structure, comprising an early strike-slip dominated pull-apart basin with restricted aerial extent and centred in the Magdalen Island area of the Gulf of St. Lawrence (Figure 3), and a later and more widespread second part as a thermal subsidence sag-basin (Reading, 1982). Although this concept has an attractive simplistic "steer's head" appeal, the Maritimes Basin is in fact much more complex than Bradley's model (see for example: Haszeldine, 1984; Fyffe and Barr, 1986; Boehner, *et al.*, 1986; McCutcheon and Robinson, 1987). In particular, the early pre-sag phase is not a single strike-slip transtensional rift but comprises a series of sedimentary and structural subbasins, or their erosional remnants, some of which lie beneath and some outside of the present boundaries of the late sag basin (Figure 3, cf. Figure 1).

The early-formed subbasins did not all develop simultaneously. Their thickest sedimentary sequences and the time of maximum subsidence range from late Middle Devonian to Westphalian C (Howie and Barss, 1975; Bradley's table 2, 1982). The subbasins as presently preserved can be divided into two groups: (1) sedimentary subbasins, and (2) structural subbasins. A sedimentary subbasin is an isolated or semi-isolated depocentre that originated by synsedimentary subsidence along a steep fault or faults and contains thick stratigraphic sequences. A structural subbasin is the remnant of a larger sedimentary basin in which the sedimentary record is preserved by post-depositional downfaulting. Subbasins range in shape from linear grabens to half-grabens, fault wedges and rhomboid pull-apart basins (Crowell, 1974a; McLaughlin and Nilsen, 1982). The two types of subbasins may be distinguished by determining the type and timing of basin-bounding faults and by the presence or absence of basin-margin sedimentary facies.

Both subbasin types commonly show evidence of structural inversion as seen by unconformities or disconformities in their stratigraphic records. This has resulted from

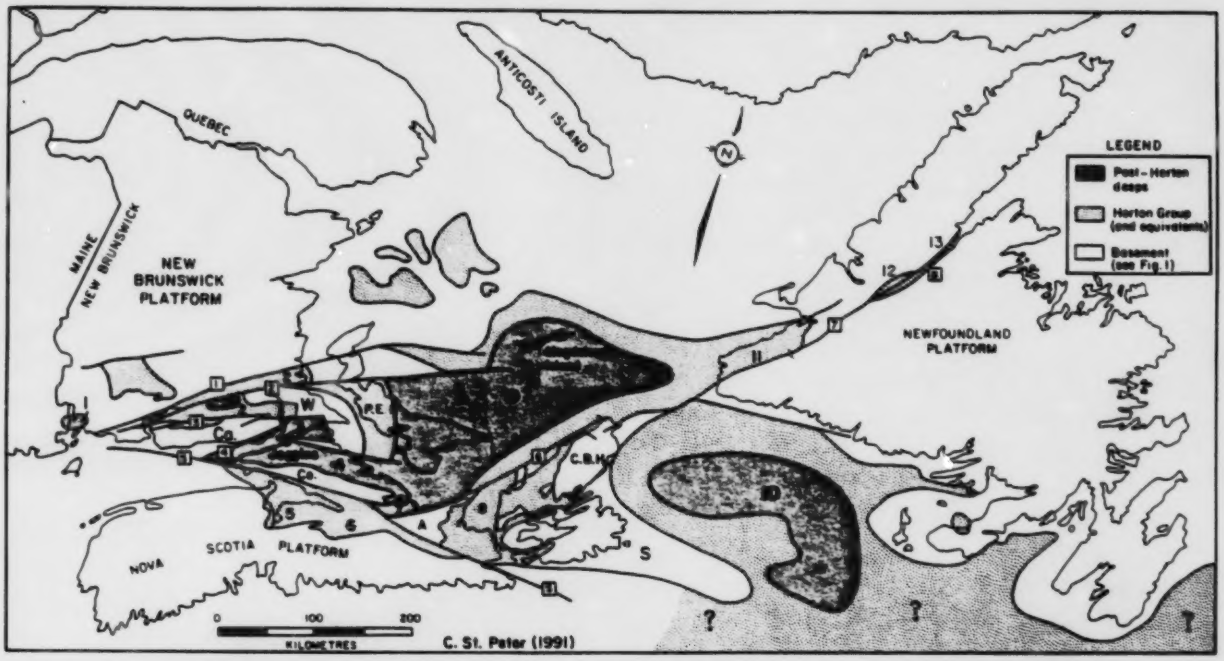
QUEBEC
ANTICOSTI ISLAND
N
MAINE
NEW BRUNSWICK
NEW BRUNSWICK PLATFORM
NEWFOUNDLAND PLATFORM
NOVA SCOTIA PLATFORM
LEGEND
Post-Horton deeps
Horton Group (and equivalents)
Basement (see Fig. 1)
1
2
3
4
5
6
7
8
9
10
11
12
13
W
P.E.
Ca
Co
A
C.B.H.
S
?
0
100
200
KILOMETRES
C. St. Peter (1991)

Figure 3: Map of subbasins and uplifts in Maritimes Basin showing distribution of Horton Group and post-Horton "deeps" where the Horton is overlain by thick (Upper Paleozoic) sections. Subbasins: 1= Perry, 2= Moncton, 3= Sackville, 4= Cumberland, 5= Minas, 6= Shubenacadie, 7= Stellarton, 8= Mabou, 9= Magdalen, 10= Sydney, 11= Bay St. George, 12= Deer Lake, 13= White Bay. Uplifts or Arches: Ca= Caledonia, W= Westmorland, Co= Cobequid, A= Antigonish, C.B.H.= Cape Breton Highlands, S= Scatarie. Faults: $\boxed{1}$= Belleisle, $\boxed{2}$= Berry Mills, $\boxed{3}$= Clover Hill, $\boxed{4}$= Harvey-Hopewell, $\boxed{5}$= Cobequid-Chedabucto, $\boxed{6}$= Hollow, $\boxed{7}$= Long Range, $\boxed{8}$= Hampden. Compiled from: Howie and Barss (1974), Wade, *et al.* (1977), Keppie (1977), Fralick and Schenk (1981), Bradley (1982), Hyde (1982), Knight (1983), van de Poll (1983), Martel (1987), Gates (1989), Ryan and Boehner (1990), Ryan, *et al.* (1990a, 1990b, 1990c), Durling and Marillier (1990), McCutcheon (1990), and St. Peter and Fyffe (1990).

basinal uplift and erosion of part of the stratigraphic column in many subbasins; consequently the former shape and origin (sedimentary or structural) of some basins remains in doubt.

The early-formed sedimentary subbasins within the Maritimes Basin are in many places cut by Carboniferous faults (Belt, 1968; Webb, 1963, 1969; Fralick and Schenk, 1981; Knight, 1983; and Leger, 1986). Where the faults have significant dip-slip displacement a structural subbasin may result from subsidence of the affected part of the parent sedimentary basin. Renewed deposition in the subsiding area can result in the simultaneous formation of a second generation sedimentary subbasin over the developing structural subbasin. Continued displacements on numerous regional faults (Belt, 1968; Webb, 1969) and consequent changes in the location of depocentres has resulted in a Maritimes Basin complex comprising in any one place one or more generations of sedimentary and structural subbasins (Kelley, 1967; Howie and Barss, 1975; Bradley, 1982).

Examples of sedimentary subbasins include the inverted Upper Devonian/Lower Carboniferous Horton sequence in the graben-shaped Moncton Subbasin as will be described in greater detail later in this report, the Upper Devonian to Lower Carboniferous Anguille Group in the Bay St. George Subbasin of Newfoundland (Knight, 1983), the Upper Carboniferous sequence in the rhomb-shaped Stellarton Basin (Yeo, 1985), the Upper Carboniferous (Westphalian C) sequences in the Sydney Subbasin (Gibling and Rust, 1986), and the Tournaisian to Westphalian C sequences in the Cumberland Subbasin (Boehner, *et al.*, 1986; Ryan, *et al.* , 1988). An example of a structural subbasin is the Upper Devonian/Lower Carboniferous Horton sequence in the rhomboid Sackville Subbasin (Martel, 1987). This structural subbasin, which is clearly seen on seismic reflection profiles, has subsequently been overlain by a second generation sedimentary basin comprising Windsor Group and younger strata (Figure 3).

The stratigraphy within the Maritimes Basin has been summarized by Roliff (1962), Kelley (1967), Hacquebard (1972), Howie and Barss (1974, 1975), Williams (1974), and van de Poll (1978). Thickness estimates indicate that up to 8 km of predominantly terrestrial clastic sediments were deposited in the basin. Regionally the stratigraphic section can be divided into five lithostratigraphic groups; in ascending order they are: Horton, Windsor, Mabou, Cumberland, and Pictou (Ryan, *et al.*, 1990a, 1990b, 1990c, 1991; Ryan and Boehner, 1990).

The early-formed subbasins commonly contain a basal section up to 5 km thick of alluvial, fluvial, and lacustrine strata and local volcanic rocks of late Middle Devonian to Lower Carboniferous (Tournaisian) age. The basal strata have a myriad of formation names, each formation being typically restricted to the subbasin containing its type section (see for example, Hacquebard, 1972; and Howie and Barss, 1974). The basal formations are assigned to the Horton Group. In the Moncton Subbasin the Horton Group includes the Memramcook, Albert, and Weldon formations (Table 1). Many of the subbasins, for example the Moncton Subbasin, underwent inversion in the late Tournaisian and as a consequence the Horton rocks are cut by innumerable brittle fault zones. Beds in or adjacent to faults are commonly steeply dipping or overturned. In most subbasins the Horton Group is unconformably or disconformably overlain by Visean strata of the Windsor Group (Knight, 1983; Smith and Collins, 1984; Utting, *et al.*, 1989). In New Brunswick, the hiatus marking the end of Horton deposition is an angular unconformity at the base of the Hillsborough Formation (Table 1). The unconformity is easily seen throughout the Moncton and Sackville subbasins on seismic reflection profiles.

Kelley (1967) defined the Windsor Group as a "partly or wholly marine sequence of strata that conformably or unconformably overlies the Horton Group and overlaps pre-Carboniferous rocks". The Windsor Group was divided by Bell (1929) into five subzones that have been interpreted as transgressive and regressive cycles (Schenk, 1969). The cycles comprise algal and brachiopod-bearing patch reefs, algal laminated carbonates, gypsum, anhydrite, salt, local potash beds, red mudstones and coarse-grained clastic rocks. The clastic rocks occur at the base of the Windsor Group (Hillsborough Formation) and as facies on the upland side and adjacent to the transgressive margins of the Windsor sea (Gussow, 1953; Schenk, 1969; Smith and Collins, 1984). The rationale for assigning the Hillsborough Formation to the Windsor Group is discussed below under Weldon Formation (pages 17-18) and Carboniferous Seismic Stratigraphy (pages 81-83). The Windsor locally overlaps the underlying Horton and lies unconformably on basement rocks (Howie and Barss, 1974, 1975; McCutcheon, 1981a; Smith and Collins, 1984). The Windsor stratigraphy in the southeastern Moncton Subbasin is given in Table 1.

Table 1: Table of formations, southeastern Moncton Subbasin and Sackville Subbasin, New Brunswick. Table in part after Norman (1941), Gussow (1953), McLeod and Ruitenberg (1978), McLeod (1980), and McCutcheon (1981a).

ERA	SYSTEM/SERIES	STAGE	GP.	FORMATION	LITHOLOGY
PALEOZOIC	UPPER CARBONIFEROUS	STEPHANIAN	PICTOU	Undivided Formations	Grey to red, fine-to coarse-grained, lithic or feldspathic and locally quartzose sandstones, grey to red, polymictic and locally quartz-pebble conglomerate, red to locally grey shale and mudstone, minor calcrete, and coal seams.
		WESTPHALIAN	CUMBERLAND	Boss Point	Grey to yellowish grey quartzose sandstone, rounded quartz-pebble conglomerate, minor red sandstone, red and grey mudstone, calcrete, and coal seams.
				Enragé	Red to locally grey conglomerate, fine-to coarse-grained sandstone; minor mudstone and calcrete.
		NAMURIAN	HOPEWELL	Shepody	Grey to red, fine-grained, laminated sandstone, red mudstone, very coarse-grained sandstone; minor conglomerate and grey mudstone.
				Maringouin	Red mudstone; minor ripple laminated sandstone.
	LOWER CARBONIFEROUS	VISEAN	WINDSOR	Clover Hill	Nodular, to mosaic and massive anhydrite, salt and claystone.
				Cassidy Lake	CASSIDY LAKE: Colourless to orange-brown, medium-to coarse-grained halite, red sylvinite; minor claystone and anhydrite.
				Upperton	UPPERTON: Grey to white gypsum at surface, nodular to mosaic anhydrite; minor stratified anhydrite.
				Macumber	MACUMBER: Grey to black intraclastic or pelletoidal wackestone and packstone; minor floatstone and intraformational breccia.
				Gays River	GAYS RIVER: Grey to black, laminated to thickly bedded algal boundstone; minor wackestone, packstone and basal bafflestone.
				Hillsborough	Red to grey granule to cobble polymictic conglomerate, red to grey lithic sandstone; minor red mudstone.
		TOURNAISIAN	HORTON	Weldon Boyd Creek Tuff	Red to locally grey mudstone, fine-to coarse-grained sandstone, granule to boulder polymictic conglomerate; minor calcrete and gypcrete. BOYD CREEK TUFF: Light pink to purple or dark grey felsic crystal-lithic tuff.
				Albert	Grey and minor red mudstone and shale, grey and minor red, fine-to coarse-grained feldspathic and lithic sandstone, grey and minor red granule to boulder polymictic conglomerate; minor kerogenous mudstone, kerogenous shale, nodular limestone, oncolitic limestone, dolostone, rock salt, anhydrite, and glauberite.
	UPPER DEVONIAN	FAM. FRAS.		Memramcook	Red to grey, granule to boulder polymictic conglomerate, red to locally grey fine-grained to pebbly feldspathic and lithic sandstone, red mudstone; minor calcrete.
	PRE-UPPER DEVONIAN			Basement Complex	Deformed to polydeformed sedimentary, metasedimentary, volcanic, and metavolcanic rocks; massive to deformed intrusive rocks.

The Windsor Group is conformably overlain by the late Visean to Namurian (A and B) Mabou Group in Nova Scotia (Boehner, 1985b; Utting, 1987b; Ryan, *et al.*, 1990a, 1990b, 1990c 1991; Ryan and Boehner, 1990), except in the Sydney Subbasin (Belt, 1965). The Mabou comprises over 800 m of mainly lacustrine and fluvial red and grey mudstones with subordinate sandstone and conglomerate (Belt, 1964, 1965; Boehner, 1985b; Ryan, *et al.*, 1991). To date only Belt (1964, 1965) has applied the name Mabou to describe those mudstones and sandstones in southeastern New Brunswick that conformably overlie the marine Windsor rocks. In this regard, Belt placed the mudstones of the Maringouin Formation and the sandstones of the overlying Shepody Formation in the Mabou. In New Brunswick the Mabou Group is equivalent to the Hopewell Group as shown in Table 1 (Norman, 1941; Gussow, 1953; van de Poll, 1978).

Norman (1941) previously assigned the Maringouin and Shepody, along with the overlying conglomerates of the Enragé, to the Hopewell Group. An angular unconformity or a disconformity at the base of the Enragé Formation can be seen on seismic reflection profiles within the Moncton Subbasin (see below under CARBONIFEROUS SEISMIC STRATIGRAPHY, pages 81-84, and Gussow, 1953). This natural tectonic break would suggest that the Enragé should be excluded from the Hopewell, as was previously recommended by Belt (1964). Instead it should be grouped with Belt's overlying coarse facies. In this regard, the Enragé Formation is herein informally included in the Cumberland Group together with the Boss Point Formation (Table 1). In the Cumberland Subbasin of northern Nova Scotia (Figure 3), the Mabou Group is conformably overlain by the newly redefined and expanded Cumberland Group (Ryan, *et al.* , 1991). The new Cumberland Group includes the rocks previously assigned to the Riversdale and Cumberland groups (Ryan, *et al.*, 1990a, 1990b, 1990c, 1991). The Cumberland Group shows rapid changes in thickness and facies from east to west in the Cumberland Subbasin. In the western part of the subbasin it may be over 7 000 m thick (Ryan, *et al.*, 1990a, 1990b, 1990c, 1991). The Cumberland strata range in age from late Namurian to Westphalian C or D. The rocks are exclusively terrestrial and predominantly coarse conglomerates and sandstones with lesser mudstones. The Cumberland Group includes many coal seams, the most famous of which are at Joggins (Figure 3) and 30 km east of Joggins at Springhill (Hacquebard, 1972).

In New Brunswick the name Cumberland Group has never been formally assigned to strata of Cumberland age (late Namurian to Westphalian C-D) or of Cumberland stratigraphic position. Bell (1944) assigned both the Enragé Formation and the Boss Point Formation to the Riversdale Group, but Ryan, *et al.* (1990a, 1990b, 1990c, 1991) have included the Riversdale beds in their expanded Cumberland Group. In accordance with this and for the purposes of this report the Enragé and Boss Point strata of New Brunswick are informally placed in the Cumberland Group (Table 1).

The distribution of the Cumberland strata in southeastern New Brunswick, shown on Plate 92-33, is based on a compilation from published maps (Norman, 1941; Gussow, 1953; Carr, 1968; Ball, *et al.* , 1981). Further work is required to define the contact between the Cumberland Group and Pictou Group, particularly in the area around Petitcodiac and north of the Kierstead Mountain Fault on the New Brunswick Platform (Plate 92-33).

The Pictou Group is the youngest sequence of Carboniferous rocks in New Brunswick. The Pictou beds paraconformably or unconformably overlie the Cumberland strata in the Cumberland Subbasin (Ryan, *et al.*, 1990a, 1990b, 1990c, 1991). Elsewhere the Pictou Group overlies pre-Cumberland rocks with angular unconformity (Belt, 1965; Hacquebard, 1972; Gibling, 1985). Recently, van de Poll (1989), from work in Prince Edward Island, has placed the Pictou Group within a newly defined Northumberland Strait Supergroup. The Supergroup comprises the Pictou Group and the conformably overlying Prince Edward Island Group. Strata in the Supergroup range in age from Westphalian C to Artinskian. The Pictou Group or, more correctly, the Northumberland Strait Supergroup forms a regionally extensive horizontal to gently-dipping fluvial and paludal coal-bearing sequence. It overlies: (1) intra-basinal basement highs, (2) most of the older and more deformed Carboniferous strata within the earlier subbasins, and (3) platformal basement terranes in New Brunswick, Nova Scotia and Newfoundland (Figure 1). The Northumberland Strait Supergroup thus defines the late regional thermal subsidence sag-basin phase of Bradley's (1982) bipartite model.

STRATIGRAPHY OF THE UPPER DEVONIAN / LOWER CARBONIFEROUS HORTON GROUP AND SUMMARY OF TECTONISM IN THE MONCTON SUBBASIN

STRATIGRAPHY OF THE HORTON GROUP

The Horton Group (*sensu stricto*) in New Brunswick is confined to the Moncton and Sackville subbasins (Figure 3 and Plate 92-33). It lies with pronounced angular unconformity upon crystalline rocks of the Avalon zone and it is unconformably overlain by coarse-grained redbed clastics of the late Tournaisian or early Visean Hillsborough Formation (Plate 92-33 and Table 1). The Group consists of the basal Memramcook Formation, the medial Albert Formation, and the upper Weldon Formation.

Memramcook Formation

The Memramcook Formation represents the first record of sedimentation in the Moncton Subbasin. The type section of the Memramcook Formation is along Stony Creek in the south-eastern part of the Moncton Subbasin in the Gaytons area (Plate 92-34). The Memramcook Formation is well exposed along the Pollett River (Figure 4a),[1] where it is in fault contact with the Caledonia Uplift (Plate 92-34). South-west of the Pollett River, Memramcook strata occur in a narrow outcrop belt lying on basement rocks in the Walker Settlement area and in a broad belt from the Wards Creek Fault to Hampton Station (Plate 92-33). To the northwest, the Memramcook is exposed between the Kierstead Mountain and Belleisle faults and in a narrow outcrop belt faulted against the Jordan Mountain basement inlier (Plate 92-33). Memramcook strata are also exposed in the Indian Mountain area north of Moncton. The distribution of the Memramcook Formation in the subsurface in the southeastern Moncton Subbasin is shown on Plates 92-35 and 92-38 to 92-47.

The stratigraphy and tectonic history of the Memramcook redbeds have been described in detail by Popper (1965). A more recent account of the lithostratigraphy of the formation has been given by Carter and Pickerill (1985b). In brief, the Memramcook Formation is composed of red and minor grey interbedded polymictic conglomerate, lithic and feldspathic sandstone, and mudstone with minor caliche.

In the type section at Stony Creek (Plate 92-34), the Memramcook Formation consists of fining-upward sequences of pebble conglomerate, trough- and tabular cross-bedded gritty sandstone (Figure 4b), and mudcracked mudstones with

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[1] **See Appendix 1 (page 133) for geographic location of all photographic figures.**

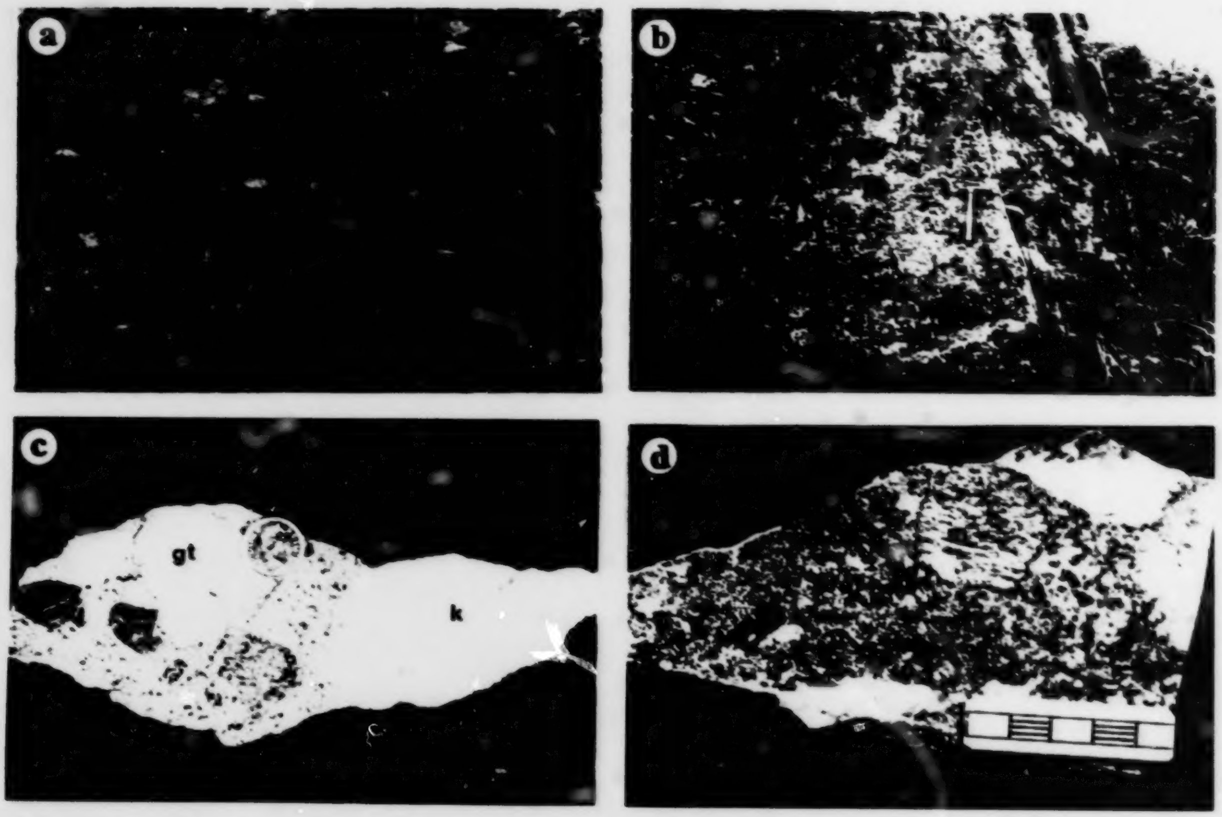

Figure 4: Memramcook Formation Lithology (a) Massive, matrix-supported, rounded-clast, pebble to boulder polymictic conglomerate at the Pollett River; (b) Coarse-grained, planar cross-bedded, feldspathic-lithic arenite and erosionally based cross-beds of polymictic pebbly sandstone (shown by dashed line). Outcrop is 100 m south of the Gaytons quarry; (c) Rounded pebbles and cobbles of cataclastic granite (gt), gabbro (gb), and potash feldspar (k) in Memramcook conglomerate at the Gaytons quarry. Coin is 17 mm in diameter; (d) Rounded pebble of laminated marble (m) in Memramcook conglomerate at the Gaytons quarry. Scale in centimetres.

locally abundant caliche nodules. The strata and bedforms indicate a probable meandering stream environment of deposition.

Paleocurrent determinations by the author on cross-beds along Stony Creek give a mean azimuth of 158° (Figure 5). Clinoforms on seismic reflection profile line 70X (Plate 92-39) also suggest a southerly transport direction. Further evidence of transport from the north is provided in the Gaytons quarry just to the north of Stony Creek where beds of conglomerate on the south quarry wall contain pebbles of granite and minor marble (Figure 4c and 4d). The marble clasts suggest the presence of Precambrian Greenhead Group rocks to the north of the quarry. The granite in the quarry is megacrystic and has potash feldspar phenocrysts up to 6 cm long. The adjacent conglomerate beds carry the same phenocrysts as subrounded pebbles.

In the Pollett River, Walker Settlement, Kierstead Mountain, Jordan Mountain and Indian Mountain sections, the Memramcook Formation is predominantly pebble to boulder polymictic conglomerates that range from matrix-supported to clast-supported. The clasts vary from angular to subrounded and are typically set in a mud or

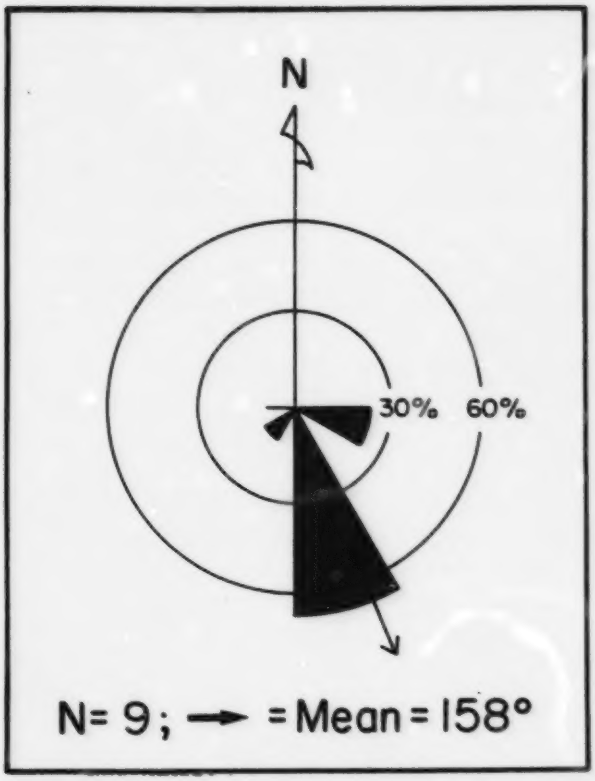

Figure 5: Memramcook Formation paleocurrent rose diagram for type section at Stony Creek.

muddy sand matrix. The conglomerate sequences contain subordinate interbeds of pebbly mudstones, muddy grits and mudstones. The absence of cross-beds or clast imbrication in the conglomerates or sandstones precludes an assessment of sediment transport vectors in the Memramcook strata in these areas. However, the coarse-grained nature of the deposits and the fact that they are typically in fault contact with basement blocks (see Plates 92-33 and 92-34) suggest a local source for the detritus.

The Memramcook beds adjacent to the basement blocks are believed to represent proximal alluvial fan deposits formed by debris flow and braided stream processes (Popper, 1965; Carter and Pickerill, 1985b) . However, the character of seismic reflections in the Memramcook away from the basement source areas suggests that the formation in the axial part of the Moncton Subbasin in the subsurface comprises a sequence of regularly interbedded sandstones (or conglomerates) and mudstones. In other words, most of the subsurface Memramcook is probably similar to the fining-upward sequences seen in the type section.

The thickness of the Memramcook Formation is virtually impossible to determine from surface sections. Complete (unfaulted) surface sections are only preserved southeast of Sussex (Plate 92-33). There the formation ranges from 600 m in thickness at Parlee Brook (McCutcheon, 1978) to about 50 m at Walker Settlement. Along the northwestern side of the Moncton Subbasin, between the Kierstead Mountain and Belleisle faults, the Memramcook sequence has a minimum thickness of 700 m. On the northwest side of the Jordan Mountain Fault, the formation is greater than 1 000 m in thickness.

The most reliable estimate of thickness in the southeastern Moncton Subbasin is made from seismic reflection profiles (Plates 92-38 to 92-47). In this regard, the unconformity between the crystalline basement rocks and the basal Memramcook Formation can be "picked" on many sections with relative confidence. The upper contact is more problematic. It is known that the Memramcook Formation is conformably and gradationally overlain by the Albert Formation (Gussow, 1953; Greiner, 1962), so the difficulty of seismically assigning a contact in these terrestrial rocks would be expected. The problem is circumvented, however, by studying seismic sections in an area where the geological contact between the Memramcook and Albert formations is well established. Such an area exists between the Stoney Creek Oil and Gas Field and Gaytons (Plates 92-34 and 92-35). There the contact between the Memramcook and Albert is known from borehole intersections and surface geology. A study of seismic profiles in this area (for example, line L70X, Plate 92-39) reveals that the Memramcook Formation is characterized by a distinctive series of reflectors. The Memramcook reflection "package" in unfaulted sections consists of a series of regularly cyclic, high amplitude reflections with moderate to good continuity. These basal Horton reflectors can be seen throughout the Moncton Subbasin on most of the migrated profiles with 30-fold or greater common-depth-point stacking. The reflectors can be followed to the southeast of the Moncton Subbasin into the Sackville Subbasin where they are seen to be the "basal reflectors" described by Martel (1987).

In the southeastern Moncton Subbasin, the basal seismic reflection facies assignable to the Memramcook Formation has a two-way-time of 180 to 400 ms (Plates 92-38 to 92-47). Sonic logs from the Irving/Chevron Little River No. 1, Irving/Chevron Stoney Creek No. 1, and Canadian Occidental Petroleum 81-8 wells (see, respectively, borehole Nos. 4, 17, and 34, Plates 92-34 and 92-35) indicate a velocity of about 4 350 m/s for the Memramcook Formation. This suggests a range in thickness of about 400 to 900 m for the Memramcook in the southeastern Moncton Subbasin.

Miospores from the Memramcook Formation near Gaytons in the type area have been dated by D. C. McGregor as probably latest Devonian (locality 6452, reported in Carr, 1968). Samples recently provided to G. Dolby from Memramcook beds on the south side or the Lutes Mountain Fault — north of Moncton, see Plate 92-33 — yield a Lower Carboniferous age (unpublished data). Dolby assigns the miospores to subzones 1B and 1C (upper part of *Emphanisporites rotatus — Hymenozonotriletes explanatus* zone) of the Lower Tournaisian (see figures 5.8 and 5.9 in Utting, *et al.*, 1989). Thus, the Memramcook straddles the Devonian/Carboniferous boundary and ranges from Famennian to lower Tournaisian in age.

Albert Formation

The Albert Formation conformably overlies the Memramcook Formation (Norman, 1941; Gussow, 1953; Greiner, 1962; St. Peter, 1982; Carter and Pickerill, 1985b). Historically, the contact between the two formations has been placed where the predominant red colour of the Memramcook beds gives way to the dominant grey of the Albert (Gussow, 1953). Seismic reflection profiles throughout the Moncton Subbasin confirm a conformable relationship between the Memramcook and Albert formations (Plates 92-38 to 92-47).

It is here proposed that the definition of the contact between the Memramcook Formation and the Albert Formation should henceforth not be based solely on a change in colour. Instead, placement of the boundary should be guided by the following lithologic criteria. **First**, in ascending the section, the boundary between the Memramcook and Albert should be placed where the section becomes predominantly shale or mudstone, regardless of colour. This criterion emphasizes including the fine-grained muddy rocks in the Albert and restricting the Memramcook to the coarse-grained or interbedded fine- and coarse-grained strata near the base of the Horton Group. **Second**, the Albert Formation should comprise the Horton section that contains sandstone beds that provide conclusive evidence of wave-generated ripples, all shale or mudstone beds with kerogenous algal laminae (lamalginites), and any beds bearing fish skeletons, fish detritus, ostracods, algal oncolites, or algal stromatolites. **Third**, the Albert Formation shall include the Horton Group carbonate, sulphate and chloride deposits that occur near Weldon and Cornhill (Plate 92-33), and which are known to interfinger with Albert clastic strata (Carter and Pickerill, 1985a, 1985b). **Fourth**, the Albert Formation should include all Horton Group beds in the Moncton Subbasin that demonstrably laterally interfinger with those strata described under criteria one, two and three.

In applying the criteria to the basal contact of the Albert Formation, it is noted that at any given locality the lowermost mudstones assignable to the Albert would not necessarily have any of the features described under criterium number two. However, the mudstones at that locality would have to be demonstrably a lateral facies of strata elsewhere in the subbasin that do contain one or more of those features. Such a situation exists in the southeastern part of the Moncton Subbasin east of the Stoney Creek Gas and Oil Field (Plates 92-35 and 92-36). The strata exposed at surface between Gaytons and the La Montagne Fault (Plate 92-34) are predominantly red mudstones with minor thin interbeds of micaceous sandstone (McLeod and Ruitenberg, 1978). The mudstones show mudcracks, rain prints and locally caliche layers or nodules. These beds have been included in the Memramcook Formation for the past fifty years (Norman, 1941; Gussow, 1953; Carr, 1968; McLeod and Ruitenberg, 1978; and Map Plate 89-104A of St. Peter, 1989). The same beds, intersected in Maritime Oilfields Ltd. No. 2 well (borehole No. 26, Plates 92-34 to 92-36), are seen to be about 600 m thick (Plate 92-36) and comprise an interstratified sequence of red and grey mudstones. Some of the grey mudstones are kerogen-bearing. The same red and grey shale sequence is only about 80 m thick north of Stoney Creek Gas and Oil Field at New Brunswick Gas and Oilfield No. 51 well (borehole No. 16, Plates 92-34 to 92-36). Seismic lines in the area (Plate 92-37) serve to confirm that the red mudstones between Gaytons and the La Montagne Fault are continuous with the sandstones and kerogen-bearing mudstones to the west. Thus, the red mudstones that have traditionally been included in the upper part of the Memramcook Formation are herein assigned to the Albert Formation.

The surface distribution of the Albert Formation in the Moncton Subbasin has been mapped by Gussow (1953), Greiner (1962), Carter and Pickerill (1985a), and St.Peter (1989). The distribution of the Albert Formation in the southeastern part or the Moncton Subbasin is shown on Plate 92-34. In the southwestern part of the subbasin (Plate 92-33), the Albert Formation crops out in a broad belt between the Kennebecasis River Fault and the Ratter Road and Wards Creek faults. The formation is exposed in a belt from Parsons Brook Fault eastward to Waterford and Urney. South of Waterford, the Albert overlies Memramcook beds at Walker Settlement. In the northwestern part of the subbasin, Albert strata occur in two outcrop belts; one between Lower Millstream and Carsonville on the northwest side of the Jordan Mountain Fault, and the other from Cornhill in the southwest continuously to McQuade Brook in the northeast.

The stratigraphy of the Albert Formation was described by Wright (1922). He divided the formation (Albert Series of his usage) into three zones. Greiner (1962) followed this lead and divided the formation into three members, which he named from oldest to youngest: Dawson Settlement Member, Frederick Brook Member, and Hiram Brook Member. In Greiner's usage the Dawson Settlement Member comprises sandstone, siltstone, shale, minor kerogenous shale, limestone and conglomerate, the Frederick Brook Member includes oil shale, calcareous shale, siltstone and limestone, and the Hiram Brook Member includes siltstone, shale, sandstone and minor kerogenous shale.

Basin-wide studies indicate quite clearly that a three-fold classical "layer cake" subdivision of the Albert Formation is unwarranted. It is not possible to erect a single vertical stratigraphic section that applies to the formation for the entire subbasin. Rapid facies changes make such a universal stratigraphic column useless and very misleading. This problem can be avoided by mapping the strata on the basis of lithologic facies as was first initiated by Worth (1977) and later convincingly argued by Carter and Pickerill (1985a) and Pickerill, *et al.*, (1985). The lithofacies in the Albert Formation have been mapped by St. Peter (1989). Lithofacies and their interpreted environments of deposition in the southeastern Moncton Subbasin are described below under ALBERT FORMATION LITHOFACIES (pages 23-81).

The thickness of the Albert Formation varies from place to place in the subbasin. Near Walker Settlement it is only about 100 m, whereas 5 km to the northwest of there on the north side of the Wards Creek Fault it is 550 m. At Carsonville the Albert is about 800 m thick. At Indian Mountain, north of Moncton, an incomplete Albert section — the base is faulted — is approximately 1 500 m in thickness.

In the southeastern part of the subbasin, the thickness has been estimated to range from 1 000 to 1 800 m (Wright, 1922; Norman, 1932; Gussow, 1953; Greiner, 1962; St. Peter, 1982; and Foley, 1989). A complete Albert section was intersected in both the Irving/Chevron Stoney Creek No.1 and East Stoney Creek No. 1 wells (borehole Nos. 17 and 18 respectively, Plates 92-34 to 92-36). The apparent thickness of the formation is 1 240 m in Stoney Creek No. 1 well and 1 216 m in East Stoney Creek No. 1 well (borehole Nos. 17, and 18, Plates 92-34 to 92-36). Assuming a dip of 20°, the true thickness of the Albert in the Stoney Creek Field is about 1 150 m. The apparent thickness (i.e., drill thickness) of the Albert section is greater than 1 680 m in the Irving/Chevron Hillsborough No. 1 well (borehole No.19, Plates 92-34 to 92-36). The well was discontinued while still in the Albert. The sonic log for the Hillsborough No. 1 well provides a sonic velocity for the Albert Formation of about 5 450 m/s from which the two-way time on seismic profile L62YA (Plate 92-41) gives a thickness of 1 650 m for the formation in the axial part of the Weldon Syncline.

The Albert Formation has an apparent thickness of more than 1 400 m in the Irving/Chevron Lee Brook No. 1 well (borehole No. 1, Plates 92-34 to 92-36). This is a minimum thickness since the Lee Brook No. 1 well did not reach the Memramcook Formation. The sonic log for the Albert Formation at Lee Brook gives a velocity of about 4 700 m/s. This velocity and the travel times from seismic profiles L13Y and L29Y (Plates 92-46 and 92-47) indicate the Albert section is approximately 2 000 m thick in the subsurface northwest of Elgin. In summary, depending on location the Albert Formation ranges in thickness from 100 to 2 000 m.

Microfloral studies by Varma (1969) on outcrop samples and well cuttings suggested an Early Carboniferous (Tournaisian) age for the Albert strata. Utting (1987a) assigned a Tournaisian age to spores recovered from outcrop samples at Boyd Creek (Plate 92-34) and from core samples of four wells in the southeastern Moncton Subbasin. Using the western European classification, Utting placed the Albert spores in the late Tn2 and early Tn3 zones. Spores from thirteen localities in the Wards Creek area south of Sussex (Plate 92-33) have been tentatively assigned by M.S. Barss to the *Vallatisporites vallatus — Pustulatisporites pretiosus* zone of probable late Tournaisian age (reported in McCutcheon, 1978).

Sixty-one widely distributed surface samples of fine-grained Albert lithotypes were provided to consulting palynologist Graham Dolby of Calgary, Alberta in 1990. His determinations have recently been received, and show miosporal assemblages ranging from subzone 1A to subzone 3B of the Tournaisian (see Utting, *et al.*, 1989 for spore zone designations). None of the samples is Devonian. In particular, spores from a locality at Irishtown north of Moncton where Greiner (1977) discovered a crossopterygian fish give a probable zone 2 age. The late Middle to earliest Late Devonian age which Greiner (1977) assigned the fish *Latvius porosus* has generally been considered too old. The new spore data suggest the Devonian fish date should be reassigned. A joint paper with Dr. G. Dolby on the new Albert palynology is being planned.

Weldon Formation

The Weldon Formation is the uppermost formation of the Horton Group in New Brunswick. It conformably overlies the Albert Formation (Norman, 1941; Gussow, 1953; Greiner, 1962; Shroder, 1963; and Carter and Pickerill, 1985b). Although numerous geologists have stated that the Weldon Formation conformably overlies the Albert Formation, none has cited a section where this is evident. There are two places where the Albert and Weldon contact is exposed. The first is on a headwater tributary of Trout Creek about 1 km east of Walker Settlement (Plate 92-33). There, reddish brown poorly sorted polymictic cobble conglomerate of the Weldon sharply but concordantly, overlies light grey, fine- to medium-grained parallel-laminated arenaceous limestone of the Albert Formation. The second locality is on Parsons Brook about 4 km southeast of Sussex (Plate 92-33). The Albert there comprises beds of grey, medium-grained, parallel- and ripple-laminated micaceous sandstone. It is conformably overlain by about 3 m of Weldon red mudstone bearing abundant caliche nodules. Interbedded red mudstone, grit, and polymictic pebble grit lie above the basal mudstone interval.

At four places in the subbasin, adjacent Albert and Weldon outcrops are separated by only a narrow concealed interval. The four localities are (see Plate 92-33): (1) along a small gulch about 1 km south of Sussex, (2) along a secondary road 800 m southeast of Bloomfield, (3) on Kennebec Brook 2 km northwest of Carsonville, and (4) along the North River near Fawcett. At all four locations parallel bedding attitudes on either side of the concealed interval imply the Albert and Weldon formations are conformable. Seismic reflection profiles throughout the Moncton Subbasin demonstrate that there is no angular discordance between the Albert and Weldon formations.

Before proceeding with a lithologic description of the Weldon Formation, a few words are warranted here to explain the nomenclatural confusion that exists regarding the formation. As noted above, Norman (1941) introduced the name Weldon Formation to describe the redbeds that conformably overlie the Albert Formation. He placed the basal Weldon contact at the base of the first redbed overlying a characteristic Albert lithotype. All later writers have essentially followed Norman's recommendation. The first problem in nomenclature arises from the fact that Norman (1941) included the Weldon Formation along with the overlying conglomerates and grits of the Hillsborough Formation in a group that he called the Moncton Group. Norman recognized that there was an angular unconformity between the Weldon Formation and Hillsborough Formation in the southeastern part of the Moncton Subbasin, and he speculated that the unconformity may be regional in extent. Gussow (1953) and Shroder (1963) observed the same unconformity and stated that it may be present throughout the subbasin, but the close similarity in rock types between the Weldon and Hillsborough formations precluded a definitive conclusion. In accordance with this, Gussow (1953) stated that the Weldon Formation should be included within the Horton Group, but that the Hillsborough Formation should be assigned to the superjacent Windsor Group with which it is conformable (McCutcheon, 1981b). Chevron Canada Resources Limited seismic reflection profiles show very clearly that there is in fact a basin-wide angular unconformity between the deformed (faulted and folded) Horton Group (including the Weldon Formation) and the overlying less deformed Hillsborough Formation (Plates 92-40, 92-41 and 92-43 to 92-47). Accordingly, in this report the Weldon Formation is used to describe the predominantly red sedimentary rocks and tuff (see below) that conformably overlie the Albert Formation, and that, in turn, are unconformably overlain by the Hillsborough Formation and/or younger strata.

It is recommended that the term Moncton Group be abandoned. An unconformity is an ideal boundary for a lithostratigraphic unit (Article 23(d) of the North American Stratigraphic Code, 1983). Consequently the recognizable angular unconformity at the base of the Hillsborough Formation provides a natural boundary between the Horton Group and Hillsborough Formation. It is further suggested that the Hillsborough Formation be assigned to the Windsor Group, as Gussow (1953) recommended nearly 40 years ago (Table 1).

A second point of potential confusion concerning the Weldon Formation is its relationship with the Boyd Creek Tuff. North of Belliveau Village, along Boyd Creek (Plate 92-34), the Weldon Formation mudstones and conglomerates contain a purple to cream yellow, felsic crystal lithic tuff that Shroder (1963) called the Boyd Creek Ash Bed and that has subsequently been named the Boyd Creek Tuff (St. Peter, 1989, Map Plate 89-104a). Gussow (1953) and Shroder (1963) assigned the tuff to the base of the Hillsborough Formation. McLeod (1980) believed that the tuff occurred in both the Weldon and Hillsborough formations and interpreted this to mean that the Weldon and Hillsborough were in part facies equivalents. This difficulty arose as a result of incorrectly assigning the coarse redbeds of the Weldon Formation at Boyd Creek and the same rocks north of Hillsborough to the Hillsborough Formation.

Borehole intersections and seismic reflection profiles convincingly demonstrate that the tuff lies within the folded and faulted Horton sequence and not within the gently dipping Hillsborough Formation, for example, the tuff has been intersected below the Hillsborough unconformity at Imperial Berryton No. 1 and Irving/Chevron Hillsborough No. 1 wells (borehole Nos. 5 and 19 respectively, Plates 92-34 to 92-36). It has also been penetrated in several wells that lie outside the known limit of the Hillsborough Formation. Wells along the south side of the Stoney Creek Gas and Oil Field, and down dip to the south of the tuff on Boyd Creek all intersected the tuff. The tuff forms a reflector that is clearly evident on seismic lines south of its known subcrop location within the Stoney Creek Field (see for example, line L62YA, Plate 92-41). The outcrop and subcrop distribution of the Boyd Creek Tuff in the southeastern Moncton Subbasin is shown on Plate 92-35.

The stratigraphic position of the Boyd Creek Tuff — a few tens of metres above the Albert/Weldon contact — has proven very useful in delineating the Weldon Syncline (Plate 92-35). In this respect it should be noted that the tuff has never been discovered in outcrop or in boreholes south of the Boudreau Fault (Plates 92-34 and 92-35).

The most comprehensive description of the distribution and lithology of the Weldon Formation is that given by Shroder (1963). The type area is along Weldon Creek in the Hillsborough area (Norman, 1941). The largest known exposure of the Weldon in the southeastern Moncton Subbasin is on the east bank of the Petitcodiac River near Belliveau Village between the Hillsborough and Saint-Joseph faults (Plate 92-34). Good reference sections (Plate 92-33) occur: (1) along Mill Brook 6 km southeast of Sussex (McCutcheon, 1978; St. Peter, 1989, Map Plate 89-104G), (2) along Mitchell Brook about 2 km south of Bloomfield (St. Peter, 1989, Map Plate 89-104H), and (3) along the North River downstream from Fawcett (Shroder, 1963; St.Peter, 1989, Map Plate 89-104K).

There is no typical stratigraphic section for the Weldon Formation. At some localities it comprises a coarsening-upward sequence from mudstones and siltstones with caliche nodules in the lower part to interbedded lithic and feldspathic sandstones, grits, and polymictic conglomerates near the top. Such coarsening-upward sections occur in Imperial Berryton No. 1 and New Brunswick Gas and Oilfields Ltd. (N.B.G.O.) No. 127 wells (borehole Nos. 5 and 9 respectively, Plates 92-34 to 92-36). At other locations it is predominantly coarse-grained throughout, for example, in surface exposures near Elgin and in Irving/Chevron Lee Brook No. 1 well (borehole No.1, Plates 92-34 to 92-36). The section intersected at Irving/Chevron Hillsborough No. 1 well (borehole No. 19, Plates 92-34 to 92-36) is 1 265 m in thickness and comprises mainly red mudstone with minor beds of fine-grained sandstone at the top and near the base of the formation. The Weldon section on the North River is also predominantly mudstone with thin interbeds of fine- to medium-grained, ripple-laminated sandstone. In several places in the subbasin the section comprises a lower coarse interval of polymictic conglomerates, grits, and minor mudstones overlain by an upper sequence of mainly red mudstones with minor interbeds of fine-grained sandstone, and conglomerate. Examples of such fining-upward sequences are seen at Mill Brook southeast of Sussex and at Mitchell Brook south of Bloomfield.

Shroder (1963) ascribed the coarse-grained lithofacies of the Weldon Formation to deposition on piedmont alluvial fans. He interpreted the interbedded shales and current-ripple-laminated sandstones along the North River as the products of fluviatile deposition. The mudstones and shales with caliche nodules and interbeds of nodular limestone are believed to be largely distal alluvial deposits, possibly in part playa sediments (Shroder, 1963), or overbank fluviatile deposits (Carter and Pickerill, 1985b).

A period of folding, faulting, uplift, and erosion followed Weldon deposition. The evidence of this is in part shown by the angular unconformity at the base of the Hillsborough Formation. As a consequence of erosion, the thickness of the Weldon is highly variable, for example, the thickness ranges from greater than 1 800 m in the axial part of the Weldon Syncline to nil at the outcrop and subcrop distributional edge of the formation on the limbs of the syncline (Plates 92-35 and 92-41, for example). In the northern part of the Moncton Subbasin, the formation is greater than 1 800 m thick in the North River section south of Fawcett (Plate 92-33). The latter thickness is a minimum estimate since the upper part of the section is cut by the Salt Springs Brook Fault.

The age of the Weldon Formation is constrained by the late Tournaisian age of the youngest Albert beds (see above, pages 16-17) and by the early mid-Visean age of the basal Windsor Group limestones (Utting, 1980). The Weldon, being predominantly redbeds, provides very little potential for palynomorph-bearing strata. Nevertheless, McCutcheon (1978) reports on an assemblage of miospores collected southeast of Sussex and east of the Parsons Brook Fault (Plate 92-33). The strata at this locality, field location No.8 in McCutcheon (1978), were placed by him in the upper part of the Albert Formation. However, the presence of red polymictic conglomerate and caliche-bearing mudstones stratigraphically below the spore locality, led St. Peter (1989, Map Plate 89-104G) to reassign the rocks at this locality to the basal Weldon Formation. The spores there have been assigned by M.E. Barss to the *Vallatisporites vallatus* — *Pustulatisporites pretiosus* zone of late Tournaisian age (McCutcheon, 1978). It is quite likely that the Weldon Formation is entirely late Tournaisian in age. This conclusion is reached by attributing the missing lower Visean time gap, that is, the time prior to deposition of basal Windsor limestones (Utting, 1980), to the pre-Hillsborough hiatus and the period of Hillsborough deposition.

TECTONISM IN THE MONCTON SUBBASIN

A brief account of the tectonic events that initiated the Moncton Subbasin and subsequently affected its sedimentary fill is given here. This is meant to advance the overview given above under Upper Paleozoic Maritimes Basin (pages 6-11), to establish a tectonic framework for descriptions of ALBERT FORMATION LITHOFACIES (pages 23-81) and ALBERT FORMATION SEISMIC FACIES (pages 81-86), and to set the stage for geological and seismic evidence of faults in the southeastern Moncton Subbasin given below under EVOLUTION OF MONCTON SUBBASIN DURING THE HORTON STRIKE-SLIP CYCLE AND SUMMARY OF SUBSEQUENT STRUCTURAL EVENTS (pages 86-100).

Paleozoic tectonic events in southeastern New Brunswick that affected the sedimentary record in the Moncton Subbasin can be divided into three cycles, conveniently named after the groups that were deposited during their period. The cycles are: (1) Horton cycle, (2) Windsor-Hopewell cycle, and (3) Cumberland-Pictou cycle. Each cycle is bounded by an unconformity or a disconformity.

Horton Cycle

The Moncton Subbasin was initiated in late Middle to early Late Devonian time following culmination of the Acadian orogeny and docking of the Avalon terrane (Donohoe and Pajari, 1974; Nance, 1986a). Evidence suggests that the compressional regime operative in the Northern Appalachians during Acadian orogenesis was oblique or transpressive (Bradley, 1982; Gates, *et al.*, 1986; Ferrill and Thomas, 1988). Devonian dextral transpression on regional ductile faults has been documented in the Avalon basement rocks in southern New Brunswick (Leger, 1986; Leger and Williams, 1986). Late Devonian dextral displacement has been called upon to explain the origin and subsequent deformation of the Upper Devonian to Lower Carboniferous Anguille Group in the Bay St. George Subbasin of Newfoundland (Knight, 1983, figure 3). Devonian and Carboniferous dextral displacement has been inferred on the Cobequid/Chedabucto Fault boundary between the Avalon and Meguma terranes (Eisbacher, 1969; Keppie, 1982; Boehner, *et al.*, 1986). The preponderance of emerging evidence strongly suggests that oblique or transcurrent tectonics was dominant during and following the Acadian orogeny. For this reason it is believed that the Moncton Subbasin was initiated by either dextral transtension or transpression in late Devonian time.

The Moncton Subbasin foundered on regional faults. The northwestern margin of the subbasin is defined by a fault system between the subbasin and the New Brunswick Platform. Faults in this system include the Kierstead Mountain Fault in the southwest and the Belleisle Fault in the northeast (Plate 92-33). Poorly sorted, angular-clast polymictic conglomerates of the Memramcook Formation form a continuous belt along the southeastern side of the Kierstead Mountain Fault. The conglomerates are interpreted as proximal alluvial fan deposits (Popper, 1965), and are taken as evidence that the present margin of the subbasin closely reflects the location of the late Devonian margin.

The southeastern margin of the Moncton Subbasin is more complex than the northwestern boundary (Plates 92-33 and 92-34). In the southeast, the contact between the subbasin and the Caledonia Uplift is in part controlled by a broad 5 to 10 km wide strike-slip fault complex. From northeast to southwest the names of the major bounding faults are: Dorchester, Caledonia, Prosser Mountain, Gordon Falls, and Clover Hill. In the southwest, from 7 km northeast of Walker Settlement to 10 km southwest of Hillsdale, the subbasin boundary is defined by unconformities: (1) a pre-Horton unconformity in the northeast, and (2) a pre-Hillsborough unconformity in the southwest (Plate 92-33).

The present-day fault-controlled southeastern boundary of the subbasin closely approximates the location of the initial Devonian boundary. This is implied by facies relationships and detritus composition in Horton Group strata. The Memramcook, Albert, and Weldon formations along the southeastern side of the subbasin contain abundant proximal debris flows and high-gradient braided stream deposits (Norman, 1941; Gussow, 1953; Oldale, 1959; Greiner, 1962; Shroder, 1963; Popper, 1965; McCutcheon, 1978; St. Peter, 1982, 1989; Carter and Pickerill, 1985b; and Carter, 1985). Clasts in the beds are mainly metasediments, metavolcanics and plutonics attributable in provenance to Coldbrook Group rocks of the Caledonia Uplift.

Following initiation on marginal faults in Late Devonian time, the Moncton Subbasin continued to subside along those faults throughout Horton time until the late Tournaisian or early Visean (Lower Carboniferous). Greater than 3.5 km of terrestrial clastics were deposited in parts of the subbasin (Plates 92-41, 92-46 and 92-47).

The Horton tectonic cycle closed in late Tournaisian time with the resultant inversion of the Moncton Subbasin. Most evidence indicates that the subbasin closed by right-lateral transpression (for details see below under INVERSION OF THE HORTON SECTION, pages 89-93). Evidence of Horton tectonism includes: (1) reactivation of basin-margin faults, (2) formation of new faults that deform the Horton section but pre-date the Windsor Group (Plates 92-38 to 92-47), (3) generation of macroscopic and mesoscopic folds in Horton strata with axes typically oblique to strike-slip fault traces (Plate 92-34), (4) formation of intra-basinal arches, that are evidenced, for example, by the exposed basement rocks at Gaytons, Jordan Mountain, and Indian Mountain (Plate 92-33), and (5) a major period of erosion particularly over rising arches where, in places, the entire Horton Group has been removed, for example over the Westmorland Uplift (Plate 92-35).

Windsor-Hopewell Cycle

The Windsor-Hopewell tectonic cycle began with renewed subsidence. The first evidence of subsidence is the widely distributed but relatively thin (0 - 400 m) Hillsborough Formation. The regional variations in thickness of the Hillsborough indicate unequal rates of subsidence, for example, the Hillsborough Formation pinches out over the crest of the Westmorland Uplift (Plates 92-41 to 92-43, and 92-45), thus explaining why the formation was not intersected in the Irving/Chevron Middlesex No. 1 well (borehole No. 3, Plates 92-34 and 92-35). The most rapid subsidence during this time seems to have been in the area from Lower Millstream to Havelock (Plate 92-33) where the Hillsborough Formation is at least 400 m thick.

Subsidence during the early part of the Windsor-Hopewell cycle was not a result of movement on basin-bounding faults as was the case during the Horton cycle. Evidence for this includes: (1) the very gradual changes in thickness of the regionally distributed Hillsborough Formation, (2) the absence of any apparent changes in lithofacies in the Hillsborough that would, for example, suggest proximal/distal relationships (the formation is nearly exclusively coarse-grained), and (3) the widespread preservation of the basal Hillsborough unconformity; which typically onlaps basement and Horton rocks without showing evidence of syndepositional faulting (Plates 92-33 and 92-34). Therefore, subsidence during the Hillsborough part of the cycle is thought to have resulted from downflexing or local sagging of the subbasin.

The local sagging that began in Hillsborough time spread to the entire Maritimes Basin by the Middle Visean as indicated by inundation by the Windsor sea (Schenk, 1969; McCutcheon, 1981b; Knight, 1983). Rapid subsidence and impoundment of the sea in local subbasins in Windsor time is inferred from several kilometre-thick evaporite (sulphate and chloride) sequences in the Moncton, Sackville, Cumberland, and Magdalen subbasins (Figure 3, and Howie and Barss, 1974; Boehner, 1985a; Howie, 1988).

By late Windsor time, and continuing through Hopewell time, faulting within individual subbasins again appears to have been the dominant control on subsidence. Schenk (1969), Howie and Barss (1974), McCutcheon (1981b), and Knight (1983) have demonstrated the presence of coarse alluvial conglomerates along the margin of some subbasins in the upper part of the Windsor section. In a similar way, Hopewell Group deposits in the western part of the Moncton Subbasin near the Caledonia Uplift comprise mainly coarse polymictic fanglomerates (Gussow, 1953). The proximal marginal conglomerates there give way to the north to distal red mudstones and fine-grained sandstones in the axial part of the subbasin (Anderle, *et al.*, 1979; McCutcheon, 1981b; Waugh and Urquhart, 1985). Seismic evidence of facies changes in the Hopewell Group is given below under CARBONIFEROUS SEISMIC STRATIGRAPHY (pages 81-84).

The Windsor-Hopewell cycle closed during the Namurian (Table 1). Evidence of tectonism is shown by renewed displacements on faults, particularly faults that were previously responsible for deformation of the Horton strata. A number of these faults in the southeastern Moncton Subbasin do not offset the unconformably overlying Cumberland Group strata. Examples include the Gordon Falls, Belliveau, Prosser Mountain, and Hillsborough faults (Plate 92-34). However, the most obvious evidence of tectonism is the cessation of sedimentation, and the initiation of uplift and erosion resulting in a pre-Cumberland angular unconformity or disconformity (Table 1). In the southeastern Moncton Subbasin, east of Turtle Creek stream, Hopewell beds are missing below the unconformity (Plates 92-34, and 92-38 to 92-42).

There was no folding associated with tectonism at the end of the Windsor-Hopewell cycle. Seismic reflection profiles (Plates 92-38 to 92-47) suggest only a gentle tilting of the Windsor and Hopewell beds prior to Cumberland deposition. The only places where Windsor and Hopewell strata show moderate or steep dips is in proximity to faults and/or in sections affected by salt tectonics (Waugh and Urquhart, 1985; Howie, 1988).

Cumberland-Pictou Cycle

The Cumberland-Pictou tectonic cycle was initiated in late Namurian or early Westphalian time by a regional phase of gentle subsidence that affected the entire Maritimes Basin. The crustal downwarping associated with this event was considered by Bradley (1982) to have resulted from thermal subsidence of the lithosphere following an earlier phase of lithospheric stretching and thinning during basin inception. Sedimentation was locally rapid; for example, in the Cumberland Subbasin (Figure 3), the Cumberland Group varies in thickness from about 3.5 km in the east to greater than 5 km in the west (Boehner, *et al.*, 1986; Ryan, *et al.*, 1990a, 1990b, 1990c, 1991). However, sedimentation was apparently slower outside the major Cumberland-age depocentres; for instance, on the New Brunswick Platform (Figure 3) present-day (erosional) records of early Westphalian to early Permian sections range from 0 to about 2 km in thickness (Howie and Barss, 1974). The sedimentary deposits were largely the products of high sinuosity rivers giving predominantly northeast-directed transport vectors suggesting a distant southwesterly source (van de Poll, 1970, 1983, 1989; Hacquebard, 1972).

The subsidence and sedimentation phase of the Cumberland-Pictou tectonic cycle ended in post-Early Permian to pre-Late Triassic time with a final period of uplift and deformation. An angular unconformity at the base of Late Triassic-Early Jurassic terrestrial redbeds of the Fundy Group on the south and north shores of the Bay of Fundy is evidence of the uplift and erosion resulting from this event (Klein, 1962; Bujak, 1979; Olsen and Baird, 1982; Nadon and Middleton, 1984).

In the Moncton Subbasin, the final tectonism affecting the Pictou Group and older rocks is shown by: (1) renewed faulting, particularly on dextral and dextral reverse faults along the northwestern side of the subbasin (Webb, 1963, 1969) such as the Berry Mills and Belleisle faults (Plate 92-33), (2) gentle macroscopic folds, such as the Marchbank, Case and Havelock synclines, and (3) local doming resulting from flowage of Windsor Group salt into pillows and diapirs. Commercial potash deposits are presently being mined in two such salt ridges, one in the Marchbank Syncline north of Hillsdale and the second in the Penobsquis area 8 km northeast of Sussex. The northeastern end of the Penobsquis salt pillow is shown on seismic profile L29Y (Plate 92-47). Note the faults associated with doming along the crest of the structure.

In summary, the tectonostratigraphic history of the Moncton Subbasin is characterized by three tectonic cycles herein named: Horton, Windsor-Hopewell, and Cumberland-Pictou. Each cycle comprises three parts, (1) an initial phase of fault-controlled or thermal-related subsidence, (2) a medial phase of continued subsidence and sedimentation, and (3) a closing phase of compression or transpression, uplift, and erosion.

ALBERT FORMATION LITHOFACIES

GENERAL STATEMENT

The Albert Formation is divided into six lithofacies. The lithofacies are designated by their characteristic rock types and by a letter symbol, thus: (1) conglomerate facies (Ac); (2) sandstone facies (As); (3) mudstone facies (Am); (4) mudstone/sandstone facies (Ax); (5) kerogenous mudstone facies (Ak); and (6) evaporite facies (Ae). Field experience has shown that the Albert Formation can be further subdivided into several subfacies (Carter, 1985; Carter and Pickerill, 1985a; Smith, *et al.*, 1991), but for the purpose of presenting regionally mappable units at 1:20 000 scale, six lithofacies are the best compromise. Lithofacies maps at 1:20 000 scale of the Albert Formation throughout the Moncton Subbasin are available (St. Peter, 1989).

The six Albert lithofacies occur in the southeastern Moncton Subbasin (Plate 92-36). In the same area, several hundred kilometres of multi-channel seismic reflection profiles are available (Plate 92-37). Since one of the purposes of this report is to determine if the Albert lithofacies give rise to distinctive seismic facies, only the lithofacies in the southeastern Moncton Subbasin are described in detail in this report.

The surface distribution and geology of the Albert Formation in the southeastern Moncton Subbasin are shown on Plate 92-34, the surface and subsurface distributions of the formation are displayed on Plate 92-35, and an outcrop and subcrop map of the Albert lithofacies is presented on Plate 92-36. It should be noted that the Albert Formation is largely concealed by younger Carboniferous strata (Plates 92-34 and 92-35) and, consequently, the subcrop lithofacies distributions shown on Plate 92-36 are assessments from borehole intersections, downdip extrapolations from surface exposures, and interpretations of seismic reflection facies (see below under ALBERT FORMATION SEISMIC FACIES, pages 84-86). On Plate 92-36, displacements by faults and shortening due to folds have not been removed. Plate 92-36 is a map without dip restoration of the beds. It shows the known distribution of Albert lithofacies as seen in outcrop and the interpreted distribution of those lithofacies in the subsurface. The lithofacies shown on Plate 92-36 represent: (1) facies at the top of the Albert Formation where the Albert is conformably overlain by the Weldon Formation (cf., Plate 92-35); and (2) facies below the top of the Albert Formation where the formation is exposed at surface or where it is unconformably overlain in the subsurface. See Plates 92-34 and 92-38 to 92-47 for the distribution of subsurface unconformities.

Evidence shows that the Albert Formation sediments are predominantly lacustrine deposits that are associated with upland mudflat and alluvial fan sequences. Consequently, the sediments display a complex basin-wide lateral transition from coarse-grained, near-source, proximal deposits to finer grained within-lake distal deposits. The lithofacies are described below, beginning with the coarse-grained strata and finishing with the fine-grained lacustrine sequences.

CONGLOMERATE FACIES (Ac)

The conglomerate lithofacies comprises grey to greenish grey and locally red polymictic conglomerate, fine- to very coarse-grained sandstone, and minor mudstone, kerogenous mudstone, kerogenous shale and limestone.

Distribution and Stratigraphy

The best exposures of conglomerate are along the Pollett River near Elgin (Plates 92-34 and 92-36). Outcrops there are seen to greatest advantage during lowest water level in the summer or fall. Other good sections occur along Webster Brook south of Elgin, along small tributaries of Prosser Brook, Turtle Creek, and Weldon Creek, and on the east bank of the Petitcodiac River between the Taylor Village and Boudreau faults. In the southwestern Moncton Subbasin, the conglomerate facies is well exposed on several brooks near Walker Settlement and Waterford, and to the west along streams on the north side of the Wards Creek Fault (Plate 92-33).

The conglomerate section along the Pollett River is greater than 1 km in thickness. There, the base of the section is faulted out by the Pollett River and Mapleton faults, and the upper part is sheared against the Weldon Formation along the Elgin Fault. At Prosser Brook, conglomerates are cut by the Caledonia and Boudreau faults. The most complete section in that area is about 550 m thick. The conglomerate section along the north-flowing tributaries of Weldon Creek is about 250 m thick. This is a minimum thickness since the lower part of the interval is cut out by the Caledonia Fault. Subsurface conglomerate intervals in Imperial Berryton No. 1 and Maritime Oilfields No. 27 wells (borehole Nos. 5 and 10, respectively, Plates 92-34 to 92-36) are respectively 500 and 650 m in thickness. The 500 m estimate for the Berryton well is a true thickness calculated from core to bedding angles given in the company litholog.

Before describing the various lithotypes comprising the conglomerate facies, a brief review of the spatial distribution and stratigraphy of the conglomerate facies within the Albert Formation will be reviewed. The facies occurs in four areas in the southeastern Moncton Subbasin (Plate 92-36). In each place it defines the locus of a separate(?) alluvial fan/fan delta complex (see below under Depositional Environments, page 37). Three of the fan complexes occur along the south margin of the Moncton Subbasin adjacent to faults bounding crystalline rocks of the Caledonia Uplift. The three southern fans are centred around Elgin, the Prosser Brook headwaters, and Caledonia Mountain to Boudreau Village (Plate 92-36). The fourth fan occurs in the northern part of the map area on the south flank of a buried basement high, the Westmorland Uplift. This fourth fan is situated east of the community of Turtle Creek and west of the Stoney Creek Gas and Oil field. The fourth fan, nowhere exposed, is only known from borehole logs and seismic interpretations.

The stratigraphy of the fan at Elgin is inadequately known. Numerous faults with probable dip-slip and strike-slip displacements preclude a detailed understanding of fan stratigraphy. Stream sections, borehole information (Irving/Chevron Lee Brook No. 1 and Imperial Oil Pollett River No. 1; borehole Nos. 1 and 2, Plate 92-36), and the fault interpretation shown on Plate 92-36 suggest that the conglomerate facies (Ac) near Elgin occurs mainly at two stratigraphic levels in the Albert Formation. The thickest conglomerate interval occurs in the lower part of the formation. The beds exposed along the Pollett River at Elgin are part of this sequence. The lower conglomerate interval is separated from the underlying Memramcook Formation by a section of grey and red mudstones of the mudstone facies (Am). The mudstones are seen to immediately overlie the Memramcook between the Gordon Falls and Pollett River faults near Pleasant Vale (Plates 92-35 and 92-36). The conglomerates exposed southwest of Goshen on the north side of the Clover Hill Fault (Plates 92-35 and 92-36) and those intersected in Irving/Chevron Lee Brook No. 1 and Imperial Pollett River No. 1 wells (borehole Nos. 1 and 2, Plate 92-36) are correlated with the lower conglomerate interval.

The upper conglomerate of the Elgin fan occurs in the upper part of the Albert Formation. It is exposed above sandstone facies (As) on Popple Intervale Brook and Colpitts Brook. The upper conglomerate interval is about 250 to 300 m thick in surface sections. It apparently thins rapidly toward the northwest; for example, it is not present in Irving/Chevron Lee Brook No. 1 (see abbreviated log of borehole No. 1, Plate 92-36). Note that this relationship could also be interpreted as implying substantial lateral displacement on the Elgin, Kay Settlement, and Lee Brook faults.

Conglomerate facies (Ac) in the fan complex at the headwaters of Prosser Brook also occurs at two stratigraphic levels. The lower conglomerate occurs in the cores of two small north-plunging anticlines that are sheared against the Caledonia Fault west of Rosevale (Plates 92-35 and 92-36). These lower conglomerates lie immediately below kerogenous mudstone facies (Ak).

The upper conglomerate interval at Prosser Brook lies above kerogenous mudstone facies (Ak), sandstone facies (As), and mudstone facies (Am) (Plate 92-36). It is overlain by the Weldon Formation (cf., Plates 92-35 and 92-36). Surface sections suggest the upper conglomerate is several hundred metres in thickness. It is correlated with the upper conglomerate interval at Imperial Berryton No. 1 (see abbreviated borehole log No. 5, Plate 92-36), which is 500 m thick.

The fact that there are two separate conglomerate intervals at Prosser Brook and also probably two intervals at Elgin, suggests either a single large alluvial fan/fan delta complex or two separate fans for which the tectonic control on each was sufficiently closely linked in time as to cause a merging of coarse facies. Without evidence to the contrary, the lower and upper conglomerates at Prosser Brook are correlated with the lower and upper conglomerates (respectively) at Elgin, thereby implying a lateral continuity of facies in the subsurface between Parkindale and Prosser Brook (Plate 92-36). It is interesting to note that the lower conglomerate section at Elgin is much thicker than the upper conglomerate interval (about 1 000 m versus 250 m), whereas the opposite seems to be the case at Prosser Brook. This could imply that the most active site of coarse clastic detrital input shifted eastward along the basin margin from early to latest Albert time.

The third alluvial fan/fan delta complex on the south side of the Moncton Subbasin occurs adjacent to the Caledonia Uplift between Caledonia Mountain and Boudreau Village (Plate 92-36). Most of this fan is concealed below the Hillsborough Formation and younger rocks (cf., Plates 92-34 and 92-36). The Albert rocks in the area are cut by several northeast- and northwest-trending faults, causing considerable difficulty in determining the stratigraphic position of the conglomerates within the Albert Formation in this fan.

In the third fan, the exposed conglomerates between Caledonia Mountain and Peck Creek occur in the upper part of the Albert Formation. These conglomerates have been assigned to the basal part of the Weldon Formation by Wright (1922), Norman (1941), Gussow (1953), and Shroder (1963). McLeod (1980) raised their status to formational rank and described them under a new name: Round Hill Formation. McLeod (1980, p. 7) further assigned the Round Hill conglomerates a stratigraphic position encompassing the entire Albert Formation and part of the underlying Memramcook Formation on the belief that the conglomerates "appear to underlie the Albert Formation". The hierarchy of the Round Hill Formation of McLeod (1980) was degraded to a member within the Albert Formation by Carter and Pickerill (1985b). They argued that the Round Hill beds and similar coarse-grained Albert Formation strata are spatially restricted to the southern margin of the Moncton Subbasin. In their text, Carter and Pickerill (1985b) describe the Round Hill Member as interdigitating with the Dawson Settlement, Frederick Brook and Hiram Brook members, the latter members as described by Greiner (1962). However, in their figure 5 they show the Round Hill Member interfingering with only the upper part of the Dawson Settlement Member and the medial Frederick Brook Member (Carter and Pickerill, 1985b, p. 18).

The conglomerates east and west of Peck Creek are herein assigned to the upper part of the Albert Formation based on the following evidence:

> (1) they are overlain by red mudstones assignable to the Weldon Formation along several small tributaries of Weldon Creek.
>
> (2) the conglomerates at Boudreau Village are overlain by kerogenous mudstones and wave ripple-laminated sandstone of obvious Albert lacustrine affinity (see MUDSTONE/SANDSTONE FACIES (Ax) on pages 48-52 and on Plate 92-36). The Albert mudstones and sandstones at Boudreau Village are in turn conformably overlain by desiccated Weldon mudstones, demonstrating that the conglomerates are restricted to the Albert Formation.
>
> (3) between the western headwater tributary of Frederick Brook and the base-

ment, conglomerate facies (Ac) occurs above and interfingers with fine-grained lithofacies, including algal limestones and kerogenous mudstones (Plate 92-36). The relationship between the conglomerates in this area and the finer grained strata of the Albert Formation is convincingly shown in Canadian Occidental Petroleum Albert Mines borehole No. 7 (see Macauley and Ball (1982) for location of hole, log, and discussion).

(4) at Canadian Occidental Petroleum Albert Mines No. 81-8 well (borehole No. 34, Plates 92-34 to 92-36) the conglomerates are overlain by Weldon red mudstones and underlain by Albert kerogenous mudstones and oil shales. The abbreviated log of hole 81-8 on Plate 92-36 shows that the conglomerates and kerogenous mudstones are in fault contact.

(5) east of Frederick Brook, and in the subsurface, several hundred metres of conglomerate define the uppermost Albert Formation at N.B.G.O. Surrey No. 1 (see abbreviated borehole log No. 21, Plate 92-36).

(6) the conglomerate interval between Caledonia Mountain and Peck Creek may not be much more than 250 m thick, that is, approximately the thickness of the presently exposed section. If this is correct, then it is unlikely that the conglomerates are stratigraphically equivalent to the entire Albert Formation, which is greater than 1 600 m thick to the north at Irving/Chevron Hillsborough No. 1.

(7) there are shows of bitumen and narrow albertite veins in the conglomerates where they are juxtaposed against basement rocks along the Caledonia Fault (St. Peter, 1989, Map Plate 89-104B). This implies: (1) that organic mudrocks underlie the conglomerates between Caledonia Mountain and Peck Creek, (2) that the mudrocks have generated hydrocarbons, and (3) that the conglomerates may not be very thick, a point argued under number (6) above.

An assessment of seismic facies in the third fan suggests that conglomerate facies (Ac) may form the basal unit of the Albert Formation in the Boudreau Village area (see Plates 92-36 and 92-40, and seismic Facies AB, pages 84-85). Further evidence of this is the presence of conglomerates below kerogenous mudstone facies (Ak) on the north side of the Boudreau Fault in ARCO Boudreau No. 1 (see abbreviated log of borehole No. 31, Plate 92-36).

Drill holes north of the third (Caledonia Mountain/Boudreau Village) fan, (e.g., borehole Nos. 8, 17, 19, 33, and 35 on Plate 92-36), show no evidence of conglomerate facies (Ac), and thus the fan is interpreted to be spatially separate both from the fan at Prosser Brook on the south side of the subbasin and from the fan east of Turtle Creek on the south side of the Westmorland Uplift.

The conglomerate facies (Ac) which occurs in the subsurface east of Turtle Creek on the south side of Westmorland Uplift is known from several boreholes (see abbreviated logs of borehole Nos. 10-12, Plate 92-36). The basal part of the Albert Formation is largely conglomerate facies in N.B.G.O. No. 115 well (borehole No. 12, Plate 92-36); the medial and upper Albert beds in N.B.G.O. No. 115 have been eroded and the formation is unconformably overlain by the Cumberland Group. In N.B.G.O. No. 100 well (borehole No. 11, Plate 92-36), southwest of N.B.G.O. No. 115 well, the base of the conglomerate interval occurs 350 m above the Albert/Memramcook contact. Here again, the upper Albert beds have been removed prior to deposition of the Cumberland Group. In Maritime Oilfields Ltd. No. 27 well (borehole No. 10, Plate 92-36), south of N.B.G.O. No. 100 well, the upper Albert Formation comprises a thick conglomerate section. Evidence that the conglomerates in Maritime Oilfields Ltd. No. 27 well occupy the upper part of the Albert Formation is given by the location of the basal Weldon Formation contact and of the Boyd Creek Tuff, both of which lie just to the south and down-dip of the well. The location of the Boyd Creek Tuff is constrained by drill holes along the south side of the Stoney Creek Gas and Oilfield (Foley, 1989) and by a seismic reflector prominent on seismic lines south of the subcrop location of the tuff. The tuff subcrops below the Hillsborough Formation and in the absence of the Hillsborough, below the Cumberland Group.

The conglomerate facies in the upper part of the Albert Formation in Maritime Oilfields Ltd. No. 27 gives rise to a distinctive seismic facies which is labelled AB on seismic line L64YR (Plate 92-42). The cross sectional shape of seismic facies AB on L64YR is suggestive of a major channel or fluvial/alluvial fan complex. The observation that the conglomerate facies (Ac) occurs progressively stratigraphically higher in the Albert Formation from northeast to southwest (see the logs of borehole Nos. 12 and 11, Plate 92-36) implies a possible fan or fan-delta complex prograding into the subbasin from the northeast. A south-facing paleoslope in this part of the subbasin is supported by southerly paleoflows in the underlying Memramcook Formation at Gaytons (see above under Memramcook Formation, page 12). Paleocurrents in Albert sandstones east of the Stoney Creek Gas and Oil field also tentatively indicate a south to southwest transport direction (see below under SANDSTONE FACIES (As), pages 46-47).

The conglomerate facies (Ac) in the upper part of the Albert Formation at Maritime Oilfields Ltd. No. 27 well (borehole No. 10, Plate 92-36) occupies the same stratigraphic position as the upper conglomerate interval in Imperial Berryton No. 1 well (see abbreviated borehole log No. 5, Plate 92-36). Facies relationships in this area imply a convergence of the fan prograding south from Turtle Creek with the northerly prograding fan from Prosser Brook. This implies that the axis of the depocentre in this part of the Moncton Subbasin may have been about where the Imperial Berryton No. 1 hole is located.

Lithology

Conglomerate, by far the most abundant rock type in the conglomerate facies, is grey or greenish grey in most exposures. However, beds are locally red or red-brown along Webster Brook, and between the Round Hill and Boudreau faults in the section exposed along the Petitcodiac River at Boudreau Village. The same red-coloured conglomerates are seen along strike from the Boudreau Village section in the subsurface in N.B.G.O. Surrey No. 1 well (borehole No. 21, Plates 92-34 to 92-36). The conglomerate sections on the south flank of the Westmorland Uplift in borehole Nos. 10, 11, and 12 are also mainly red.

The conglomerate occurs in beds 5 cm to 6 m in thickness (Figure 6a). The beds range from horizontally stratified to cross-bedded to normally graded (Figure 6a, 6b and 6c). The cross-beds are mainly small- to medium-scale planar structures with low-angle to moderately dipping foresets. Trough cross-beds are locally seen in gritty conglomerates in exposures along the Pollett River (Figure 6d). Grading in the coarsest beds varies from cobble-rich intervals near the base to pebble or grit zones at the top. Grading in the finer beds is shown by pebbly zones at the base grading upwards to granular tops. Typical conglomerate exposures consist of horizontally interstratified tabular to lenticular

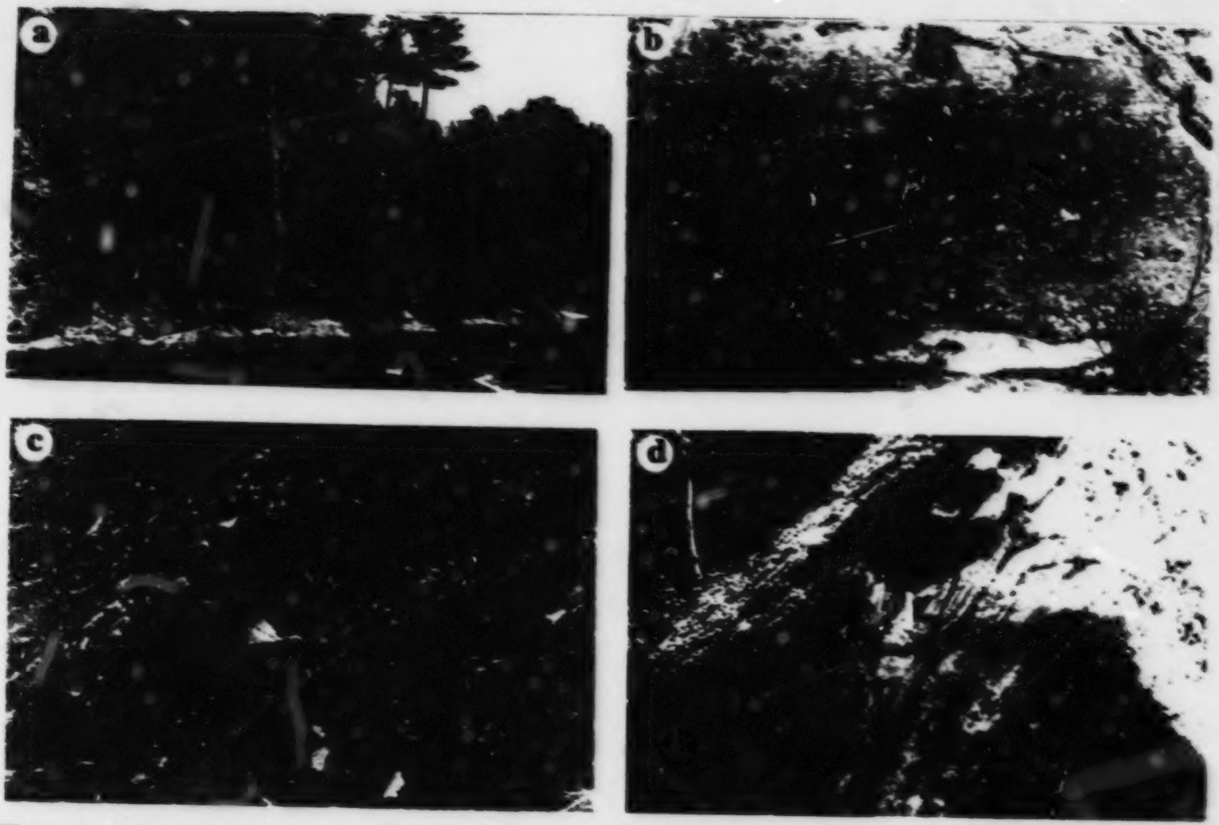

Figure 6: Albert Formation Conglomerate Facies (Ac). (a) Thickly bedded (1-3 m) conglomerate with thinner beds of sandstone (more deeply weathered and recessed) on the Pollett River; (b) Medium-scale planar cross-beds in pebble-cobble conglomerate on the Pollett River. Cross-bed foresets are parallel to hammer handle; (c) Polymictic, poorly sorted, angular to moderately well rounded clast, pebble to cobble conglomerate at Stuart Brook. Some beds are clast-supported, some are matrix-supported; (d) Small-scale trough cross-beds in gritty conglomerate at the Pollett River. Ruler is 17 cm long.

beds of widely contrasting clast sizes. For example, very thick cobble-rich beds occur together with pebble-dominated beds and granule-rich beds. In general, where outcrop is sufficiently continuous, most of the conglomerate-dominated sequences seem to fine-upward, for example, fining-upward intervals up to 10 m thick occur along the banks of the Pollett River near Elgin (Figure 7a), where the bases of intervals are in places dominated by boulders up to 30 cm in diameter. The percentage of boulders and size of clasts decrease upward in the sequences. The tops of fining-upward sequences comprise sandstone (Figure 7b), and/or sandstone with beds of mudstone, kerogenous mudstone and limestone (Figure 9d).

The conglomerate beds typically show sharp, and in many cases, erosional bases (Figures 7c and 33a). Steep-walled channels up to 2 m deep can be seen in exposures along the Pollett River and Webster Brook (Figure 7d). The channel walls are composed of sandstone and mudstone and the channel fill commonly consists of planar cross-bedded pebble or cobble conglomerate. A common feature of these cross-beds is that the azimuth of dip of their foresets is not parallel to the adjacent channel wall. An

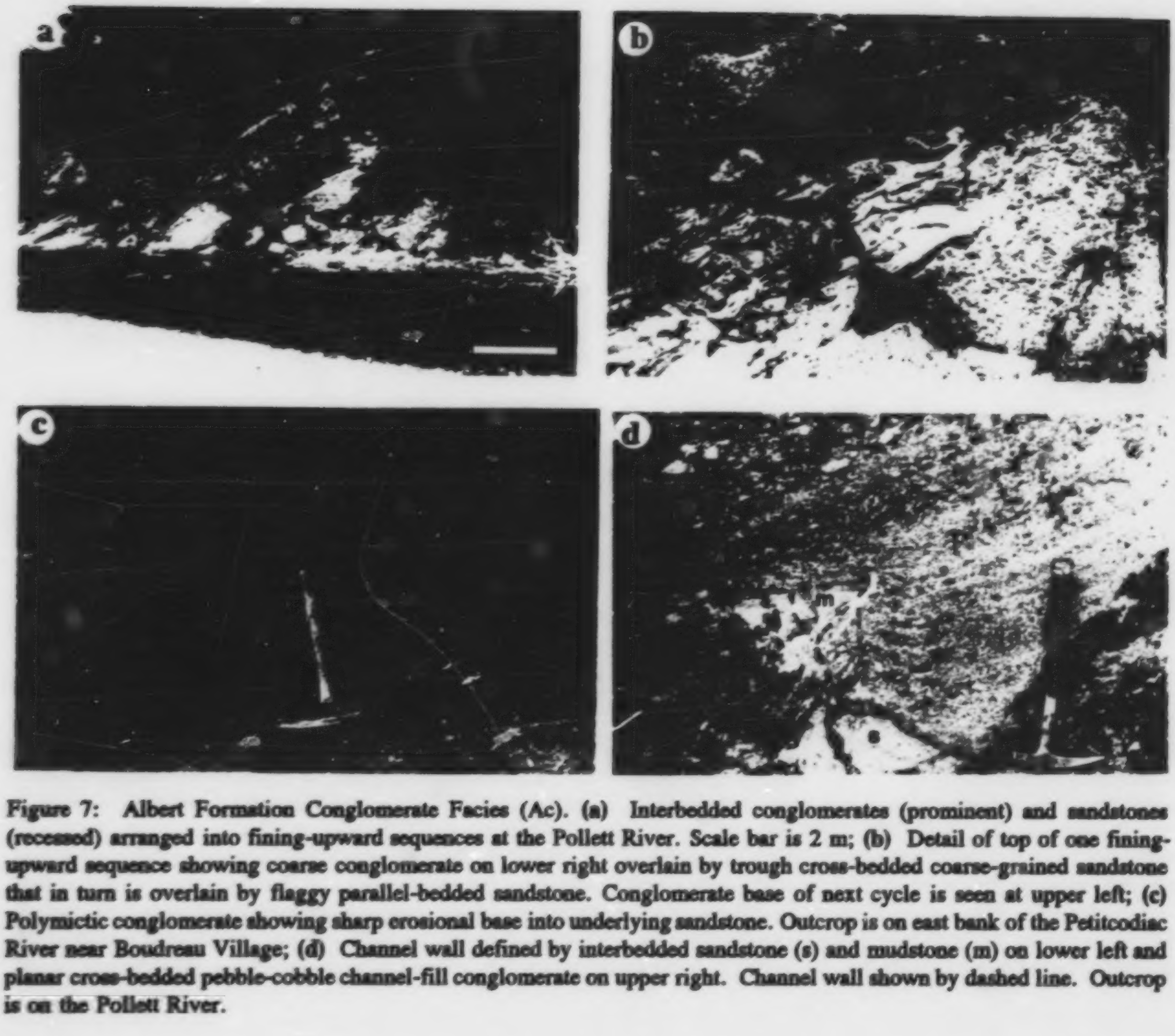

Figure 7: Albert Formation Conglomerate Facies (Ac). (a) Interbedded conglomerates (prominent) and sandstones (recessed) arranged into fining-upward sequences at the Pollett River. Scale bar is 2 m; (b) Detail of top of one fining-upward sequence showing coarse conglomerate on lower right overlain by trough cross-bedded coarse-grained sandstone that in turn is overlain by flaggy parallel-bedded sandstone. Conglomerate base of next cycle is seen at upper left; (c) Polymictic conglomerate showing sharp erosional base into underlying sandstone. Outcrop is on east bank of the Petitcodiac River near Boudreau Village; (d) Channel wall defined by interbedded sandstone (s) and mudstone (m) on lower left and planar cross-bedded pebble-cobble channel-fill conglomerate on upper right. Channel wall shown by dashed line. Outcrop is on the Pollett River.

analogous geometric relationship has been observed by Rust (1979, fig. 14) in braided rivers where planar cross-bedded gravels form by lateral outbuilding from longitudinal gravel bars.

The Albert conglomerate is poorly sorted, with clasts in some beds ranging from fine-grained sand up to boulders 30 cm in diameter (Figures 6c and 8a). The clasts vary from angular to well rounded. Grains of pebble size and larger are typically moderately well rounded to well rounded. In most cases the conglomerates have a clast-supported fabric (Figures 6c, 8a, 8b and 34d). Imbricated clasts can be seen in rare cases of well exposed horizontally stratified beds.

The following clasts have been identified in outcrop and thin section: pink and purple rhyolite, schistose rhyolite, feldspar porphyry, quartz-feldspar porphyry, fine-grained granite, pink coarse-grained granite, biotite granite, mafic volcanic, schistose mafic volcanic, sericitic

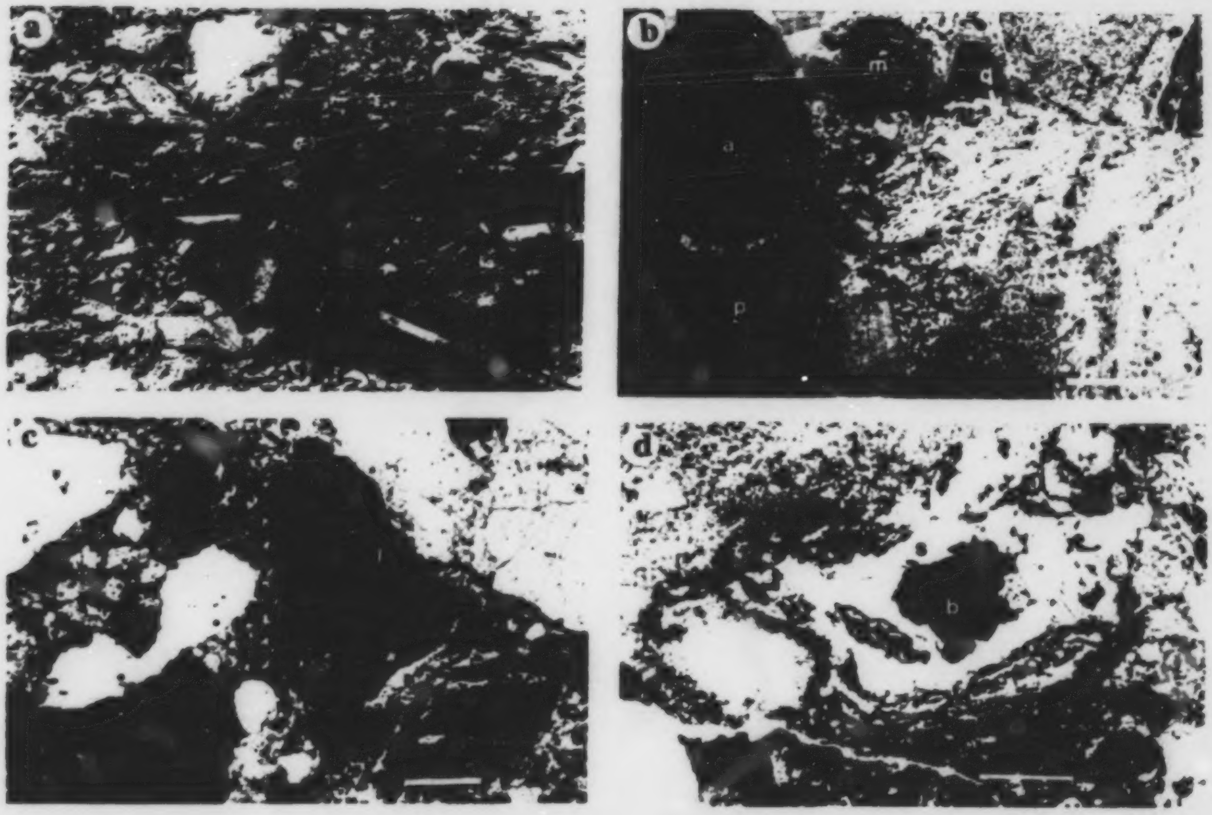

Figure 8: Albert Formation Conglomerate Facies (Ac). (a) Poorly sorted, angular to subrounded, clast-supported, polymictic conglomerate at Peck Creek; (b) Photomicrograph of clast-supported, polymictic conglomerate. Clasts include quartz-muscovite schist (q), felsic volcanic (v), quartz-feldspar porphyry (p), argillite (a), and marble (m). Plane-polarized light. Scale bar is 5 mm; (c) Photomicrograph showing intraclast of algal limestone (l) in polymictic conglomerate at Stuart Brook. Plane-polarized light. Scale bar is 1 mm; (d) Photomicrograph showing intraclast of algal laminated limestone at Popple Intervale Brook. Vug is filled with spar (s) and bitumen (b). Cross-polarized light. Scale bar is 0.5 mm.

phyllite, sericite schist, quartz-muscovite schist, diabasic gabbro, ophitic gabbro, schistose gabbro, sandstone, conglomerate, limestone, quartz, feldspar, muscovite, and biotite. The detritus is dominated by felsic volcanic and metasedimentary rocks. The limestone clasts are believed to be intraclasts. They are typically micritic and some show irregular folded or crenulated laminae suggesting a possible algal origin (Figure 8c). The siliciclastic grains are analogous to bedrock lithotypes of the Avalon terrane, which bounds and underlies the Moncton Subbasin (see above under Precambrian to Middle Devonian Basement Complex, pages 2-6, and Figure 2). See Ruitenberg, *et al.* (1979) for a description of Coldbrook Group rocks in the Caledonia Uplift.

The matrix of the conglomerates typically comprises less than 10 per cent of the rock volume. Microscopically identifiable matrix minerals include abundant chlorite and sparry calcite, and rare quartz and iron oxide(s). Dead oil or bitumen is locally present (Figure 8d).

There is widespread evidence of alteration

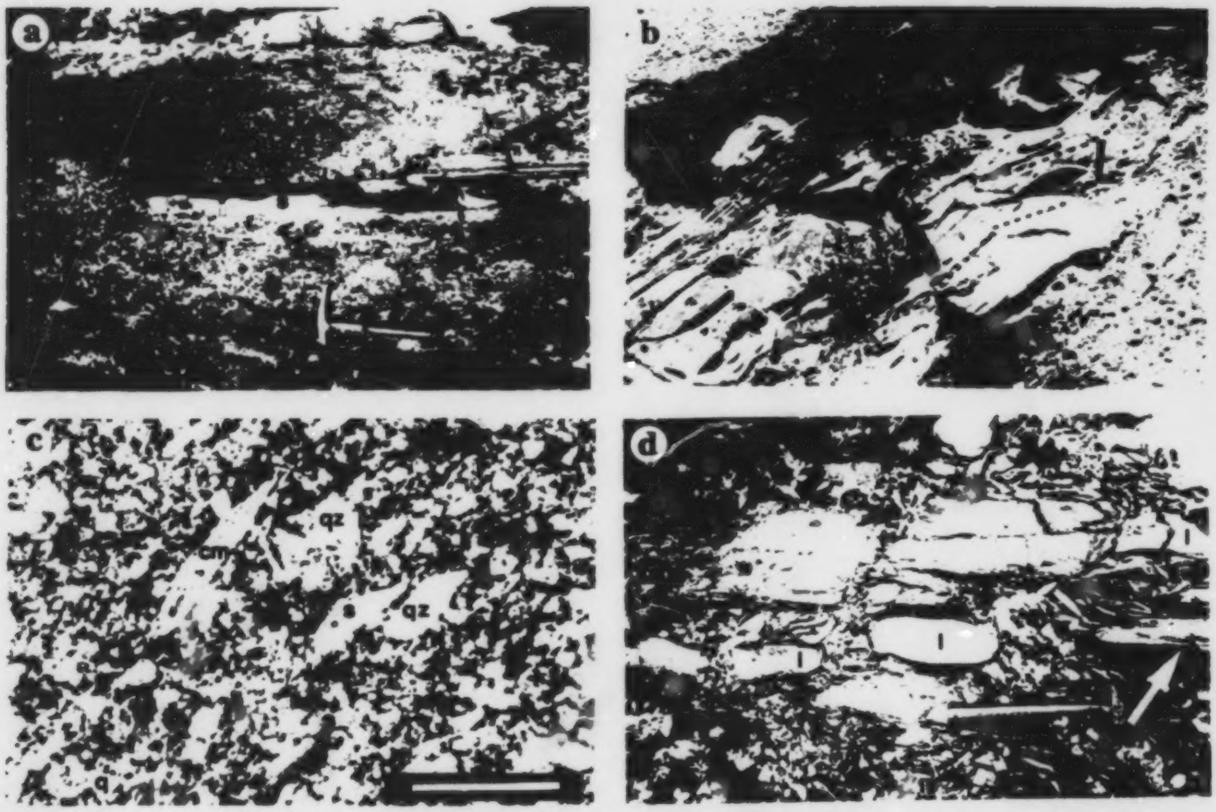

Figure 9: Albert Formation Conglomerate Facies (Ac). (a) Lenticular coarse-grained sandstone bed (s) erosively overlain by pebble conglomerate at the Pollett River; (b) Trough cross-beds in coarse-grained sandstone at the Pollett River. Foresets shown by dotted lines; (c) Photomicrograph of poorly sorted, medium-grained lithic arenite at Stuart Brook. Clasts comprise chlorite-muscovite schist (cm), sericite schist (s), quartzite (qz), quartz (q), and plagioclase (p); the later mineral shows alteration to white mica or clay minerals. Plane-polarized light. Scale bar is 1 mm; (d) Plan view of dark grey ostracod-bearing kerogenous shale with a thin interbed of buff-weathering oncolitic limestone (l) at the Pollett River. Note that limestone bed is offset by minor sinistral faults. Arrow indicates true north.

of clast minerals. Plagioclase is typically partly or wholly replaced by calcite and white mica (smectite?). Ferro-magnesian minerals and mafic volcanic grains are commonly altered to chlorite and lesser epidote.

Sandstones are the most abundant minor strata in conglomerate lithofacies (Ac). There are two quite distinct sandstone lithotypes: (1) lithic arenites; and (2) fine-grained quartzose feldspathic and quartzose lithic arenites.

The lithic arenites occur as interbeds within the coarsest conglomerate sections (Figure 6a). Sand beds of this type are typically lenticular and pinch out over several metres (Figures 7b, 7c and 9a). The lenticular character and variable bed thickness results from erosion at the base of overlying conglomerate beds. Bed thickness varies from 0 to 100 cm. Amalgamated sandstone sections, 17 m and 9 m in thickness, occur along the Pollett River and Mapleton Brook respectively.

The lithic arenite beds range from massive to graded to cross-bedded. The cross beds are predominantly small-scale planar types; trough cross-beds or channel-fill cross-beds (Reineck and Singh, 1980) occur sporadically (Figure 9b). Sandstone beds in the section at Boudreau Village range from 10 to 100 cm in thickness and grade from pebbly at the base to medium-grained at the top. The bases of the sandstone beds at Boudreau Village are sharp where they overlie mudstone. Graded sandstone beds are also seen at the Pollett River (Figure 33a).

The lithic arenites range from fine-grained to pebbly coarse-grained rocks; most are medium-grained or coarser. The finer grained beds are typically moderately well sorted, whereas the coarser layers tend to be more poorly sorted (Figure 9c). Sandstone beds of this type are compositionally indistinguishable from the matrix of interstratified conglomerates. The sand grains comprise significant quartz and feldspar and abundant rock fragments. Rock clasts are predominantly felsic volcanics and lesser mafic volcanics, with minor mica schist and phyllite, quartz-mica schist, gabbro, granite, and limestone. The matrix of these sandstones comprises microspar and spar, chlorite, and fine-grained optically unidentifiable clay mineral(s). In places, the matrix is entirely spar, which occurs as large poikilotopic crystals. Because most of the sandstones of this type contain less than 15 per cent matrix by volume they are classified as lithic arenites (Blackburn, *et al.*, 1978). Feldspars and rock fragments in these beds locally show extensive replacement by clay minerals (smectite and/or illite?) and calcite. Prior to void infilling, the sands had 3 to 10 per cent (visually estimated) intergranular and intragranular porosity. The pores are now filled with chlorite, carbonates, and accessory iron oxides and bitumen.

The second sandstone lithotype in the conglomerate facies ranges from fine-grained to medium-grained (rarely coarse-grained) and occurs in flaggy beds 1 cm to 30 cm in thickness. Sandstone beds of this type tend to be associated with mudstones and shales, rather than with coarse conglomerates. Compositionally, they range from quartzose feldspathic arenite to quartzose lithic arenite. They are compositionally indistinguishable from the sandstones that characterize the sandstone lithofacies (As) (see page 40), and like the sandstones in that facies, they contain a spectrum of current- and wave-generated traction structures. (See below under SANDSTONE FACIES (As), pages 41-43, for a description of the mineralogy and bedforms in this sandstone lithotype). As in the sandstone facies (As), the fine-grained sandstones locally have abundant plant fragments preserved along bedding planes.

Mudstone and shale constitute a minor part of the conglomerate facies (Figure 7d). Mudstone and shale occur as partings less than 1 cm wide between sandstone beds. Mudstone also occurs locally in monolithologic sections up to and greater than 20 m thick. Both mudstone and shale are, in most places, dark grey or greenish grey. However, the mudstone tends to be red in sections where interbedded conglomerates are red (see conglomerate description above, page 28).

The mudstone strata are massive to parallel-laminated. The laminae are composed of parallel or lenticular layers of silt and sand. Most beds contain slight to moderate amounts of calcite and/or dolomite mud. Some beds contain granules of sand disseminated irregularly throughout. In rare cases, mudstone strata contain accessory kerogen as dispersed grains or discontinuous laminae. Locally, the muds have desiccation cracks and nodular limestone caliche. Where the mudstones are interstratified with coarse rocks the upper contact of the mud beds is typically sharp or erosional and the lower contact is either sharp or gradational with the underlying sandstone (Figure 7d).

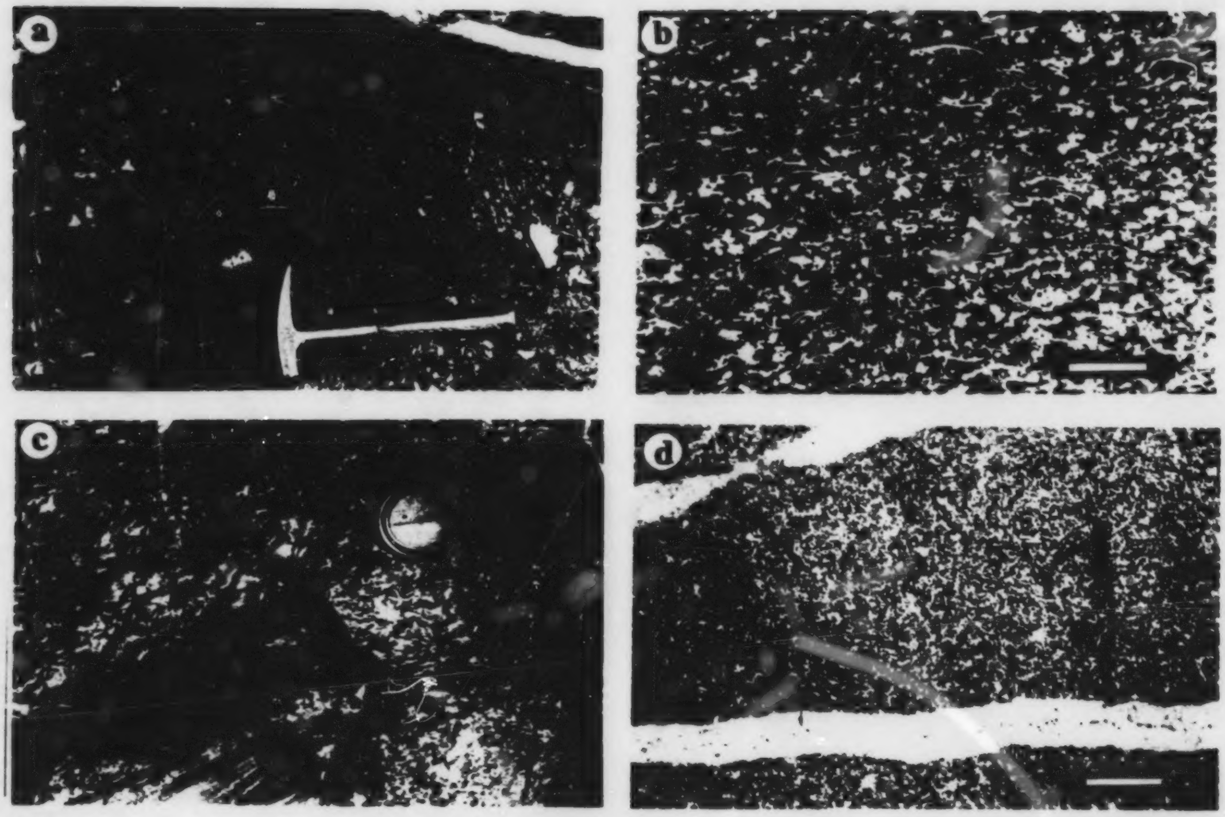

Figure 10: Albert Formation Conglomerate Facies (Ac). (a) Polymictic pebble conglomerate on right in sharp erosive contact with kerogenous shale on left. Outcrop is on Popple Intervale Brook; (b) Photomicrograph of ostracod-bearing kerogenous shale within conglomerate facies at the Pollett River. Plane-polarized light. Scale bar is 0.5 mm; (c) Limestone erosionally overlain by polymictic conglomerate west of Frederick Brook; (d) Photomicrograph of siliciclastic peloid or intraclast grainstone shown in Figure 10c. Grainstone is cut by early veins of calcite and bitumen (black) and later veins of coarse-grained calcite. Unpolarized light. Scale bar is 2 mm.

Beds of very slightly kerogenous to highly kerogenous brown shale are present in the conglomerate facies at the Pollett River, Popple Intervale Brook, Mapleton Brook, and on tributaries of Prosser Brook and Turtle Creek (Figures 9d and 10a). The kerogenous shale bed at the Pollett River contains prolific ostracod shells and rare fish scales (Figure 10b). Fissile kerogenous shale beds are eroded by a conglomerate-filled channel at the base of conglomerate facies (Ac) on Popple Intervale Brook, 600 m north of Highway 895 (Plate 92-34 and Figure 10a). The kerogenous shale beds are indistinguishable from kerogenous shale beds in the KEROGENOUS MUDSTONE FACIES (pages 65-73).

Limestone strata have been seen within conglomerate sequences in four places in the southeastern Moncton Subbasin: (1) near basement rocks west of Frederick Brook; (2) at the fault-bounded base of the conglomerate facies in the section on the east bank of the Petitcodiac River at Boudreau Village; (3) within an ostracod and fish scale-bearing kerogenous shale interval on the Pollett River 70 m north of the

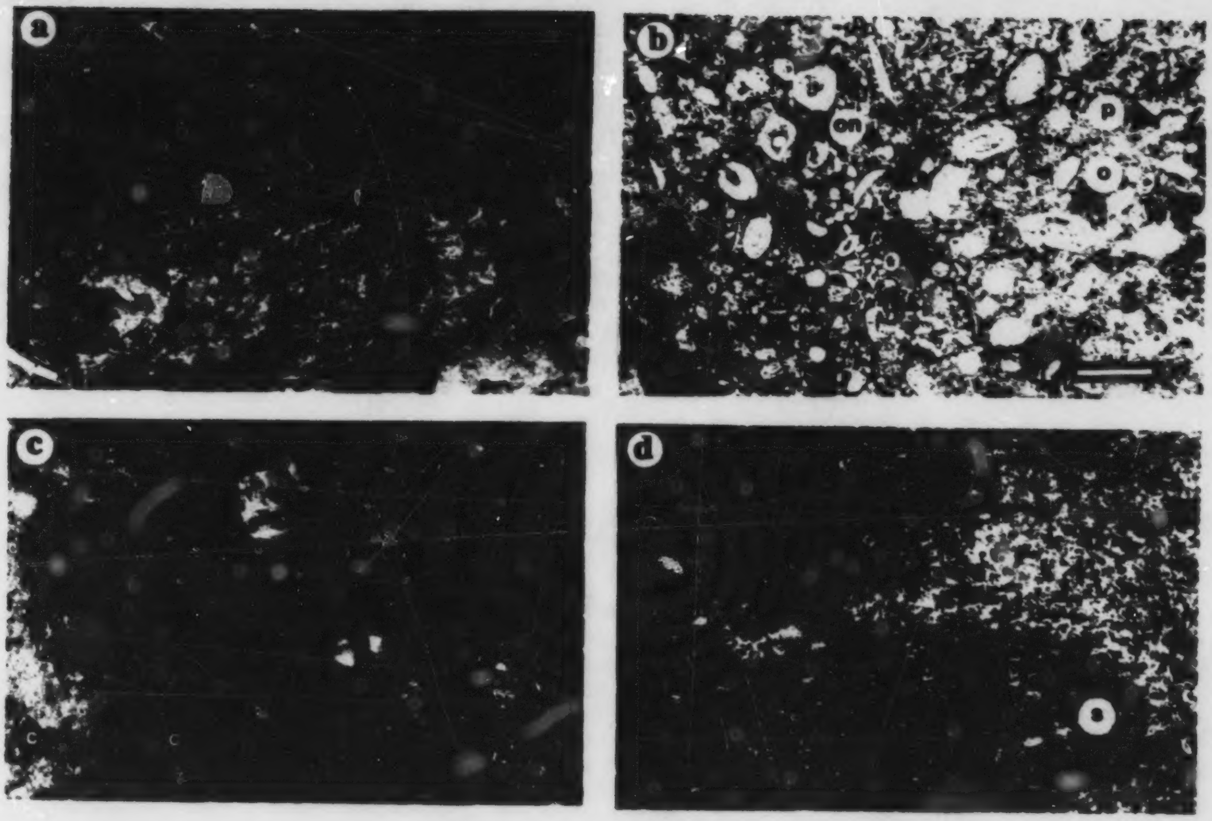

Figure 11: Albert Formation Conglomerate Facies (Ac). (a) Limestone bed erosively overlain by conglomerate in the southern part of the Boudreau Village section along the Petitcodiac River; (b) Photomicrograph of ostracodal (o), peloidal (p), oncolitic (on) packstone shown in Figure 9d. Unpolarized light. Scale bar is 2 mm; (c) Conglomeratic grainstone bed southeast of Parkindale. Siliciclastic pebbles include rounded vein quartz (q) and dark grey chert (c). Coin is 19 mm in diameter; (d) Sandy siliciclastic grainstone southeast of Parkindale. Note elongate clast of green slate (s). Coin is 19 mm in diameter.

Pollett River Fault; and (4) in a section about 25 m thick on both limbs of a syncline south of Parkindale (Plate 92-34). McCutcheon (1978) has described limestone within Albert conglomerates south of Sussex (Plate 92-33).

The limestone west of Frederick Brook is about 1 m in thickness. The lower part of the interval comprises thin beds of limestone interstratified with calcareous mudstone and fissile shale. The upper contact is sharp and erosional. It is defined by a channel 25 cm deep filled with conglomerate (Figure 10c). The limestone there is a siliciclastic peloid or intraclast grainstone (Figure 10d). The rock is characterized by parallel laminations and cross laminations defined by alternating layers rich in sand-size grains of micrite and silt to coarse-grained siliciclastic sand set in a sparry cement. It is not clear whether the micrite allochems are peloids or intraclasts.

The limestone bed at Boudreau Village is about 25 cm thick (Figure 11a). It has not been examined in thin section, but with the unaided eye it is seen to contain appreciable siliciclastic

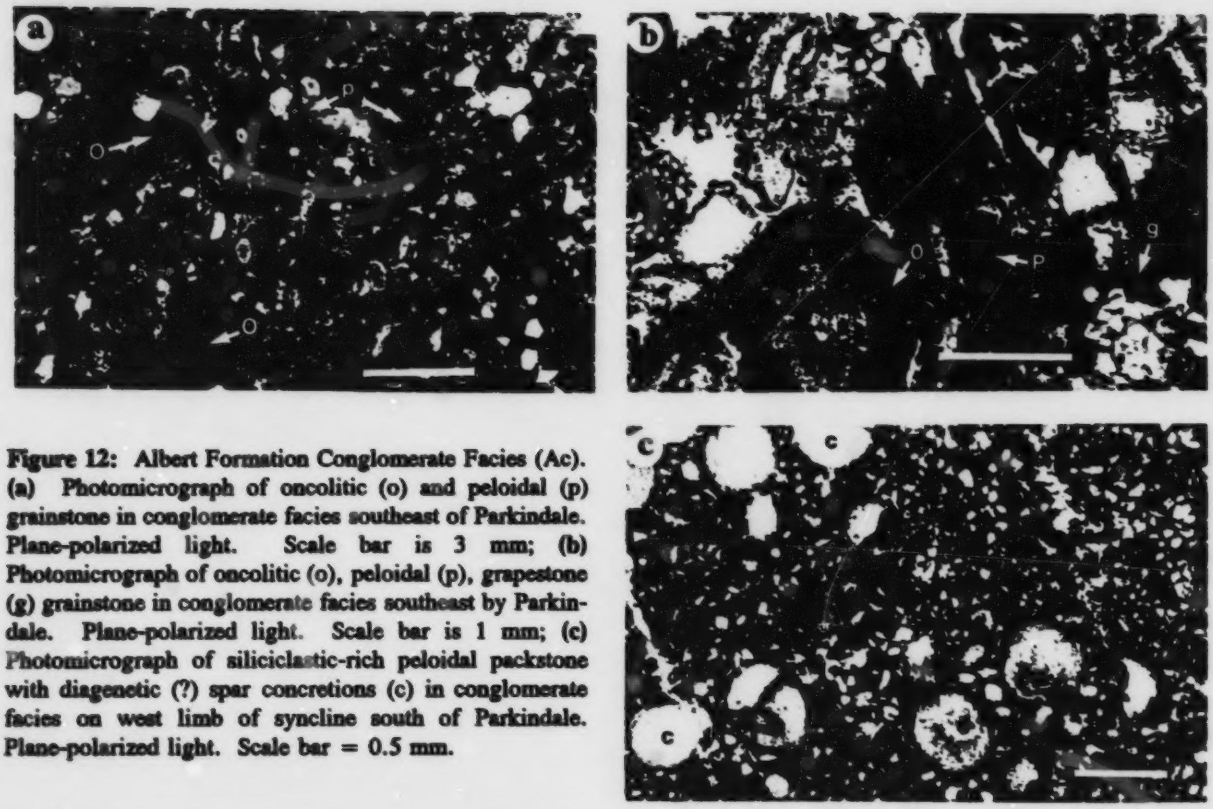

Figure 12: Albert Formation Conglomerate Facies (Ac). (a) Photomicrograph of oncolitic (o) and peloidal (p) grainstone in conglomerate facies southeast of Parkindale. Plane-polarized light. Scale bar is 3 mm; (b) Photomicrograph of oncolitic (o), peloidal (p), grapestone (g) grainstone in conglomerate facies southeast by Parkindale. Plane-polarized light. Scale bar is 1 mm; (c) Photomicrograph of siliciclastic-rich peloidal packstone with diagenetic (?) spar concretions (c) in conglomerate facies on west limb of syncline south of Parkindale. Plane-polarized light. Scale bar = 0.5 mm.

sand detritus in a crystalline sparry cement. The bed is overlain by angular-clast conglomerate.

At the Pollett River, a few beds of limestone occur in a 10.5 m thick section comprising calcareous, fine-grained, plant-bearing sandstone, calcareous mudstones, and ostracod-bearing slightly kerogenous shales (Figure 9d). Coarse conglomerates lie below and above these fine-grained lithotypes. The limestones there weather buff or brown, are dark grey on fresh surfaces, and occur in beds from 5 cm to 60 cm in thickness. The beds contain variable amounts of siliciclastic detritus. The thinner beds are nearly pure limestone whereas the thicker beds contain 10 to 20 per cent quartz, feldspar and mica of silt to granule size. The coarser beds show cross laminations defined by variations in grain size of siliciclastic and carbonate clasts. The carbonate grains comprise 3 to 4 per cent disarticulated ostracod shells, 10 to 15 per cent micrite peloids, and 20 to 40 per cent oncolites (Figure 11b). Some of the sand-size grains that consist of micrite comprise an aggregate of small peloidal bodies that look agglutinated. These grains are almost certainly of algal origin and are what Hutton, *et al.* (1980) call telalginite. The limestones at the Pollett River also contain minor fish scales. The matrix of the rock is mainly micrite and, depending on grain content, the limestones are oncolitic wackestones or packstones (Dunham, 1962).

In the syncline south of Parkindale, five different limestone lithotypes have been observed. For example, on a secondary road 1.5 km southeast of Parkindale (Plate 92-34), limestone occurs in beds 5 to 30 cm in thickness and consists of three interbedded rock types: conglomeratic, granular, and sandy limestone (Figures 11c and 11d). The siliciclastic detritus accounts for up to 25 per cent of the rocks, and the conglomerate layers contain pebbles up to 5 cm in diameter. The siliciclastic clasts are typically well rounded and include quartz, quartz-muscovite schist, felsic volcanics, minor black chert, green slate, and feldspar (Figures 11c and 11d). Carbonate allochems consist of abundant algal oncolites (some with cores of thin ostracod(?) shell fragments), and minor micrite peloids (Figures 12a and 12b). The matrix of all three lithotypes is microspar and spar and thus the rocks are oncolite grainstones under Dunham's (1962) classification. On the west limb of the syncline, about 2 km southeast of Parkindale, the limestone in two separate outcrops comprises: (1) light grey, massive to subtly laminated clean crystalline limestone; and (2) buff weathering, medium grey, parallel-laminated, fine-grained, quartzose peloidal packstone/grainstone. The latter has numerous spherical concretions of spar ranging from 0.2 to 0.8 mm in diameter (Figure 12c). The concretions show interpenetration or overgrowth texture suggesting a possible diagenetic(?) replacement origin.

Paleocurrents

A summary of paleocurrent determinations in the Pollett River and Webster Brook conglomerate sections is given in Figure 13F. Fourteen of the eighteen measurements are from tabular and trough cross-beds. Two readings are from cross laminations and the remaining two are from the azimuth of paleo-channel banks. The mean transport direction is toward the west (262°). As noted above, in both cases where channel margins have been observed at the Pollett River and Webster Brook, the azimuth of the dip of cross-bed foresets in channel conglomerates is not coincident with the azimuth of the adjacent channel wall. In other words, paleoflow determinations from cross-beds in braided streams may not reflect the actual current vector at the site of measurement (Smith, 1972). The cross-beds only indicate the direction of lateral outbuilding of longitudinal or diagonal bars (see Rust, 1979, fig. 14).

Channel banks seen at the Pollett River and Webster Brook give an azimuth of 290°. Based on this, it is tentatively suggested that the braided stream paleoflow in this part of the Moncton Subbasin was west-northwest, that is transverse to the northeast-southwest long axis of the basin. This interpretation agrees with the transport direction inferred from clast compositions of the conglomerates and coarse lithic sandstones. The clasts are similar to Precambrian Coldbrook Group rocks, which are exposed immediately south of the Moncton Subbasin within the Caledonia Uplift (Plate 92-36).

The contact between the crystalline rocks of the Caledonia Uplift and the Horton Group rocks of the Moncton Subbasin is nearly everywhere defined by major northeast-trending faults (Plates 92-33 to 92-36). Structural and seismic reflection evidence strongly suggests that the contact between the uplift and the subbasin was also largely controlled by faults during Horton time. It is argued below under MONCTON SUBBASIN MARGINS AND INFILLING BY HORON FACIES, pages 87-89, that vertical movement(s) on the basin-bounding faults were responsible for basin formation, and subsequently accommodated the Horton subsidence. A consequence of this interpreted paleogeography is that relief on northeast-trending faults gave rise to a northwest-dipping paleoslope.

Depositional Environments

The conglomerate facies is interpreted as predominantly the product of alluvial fan braided stream deposition, and nearshore lacustrine (fan-delta) deposition. The poor sorting, immature composition, planar cross-bedding, subordinate trough cross-beds, lenticular bedding, cut-and-fill features, and fining-upward cycles of lithotypes

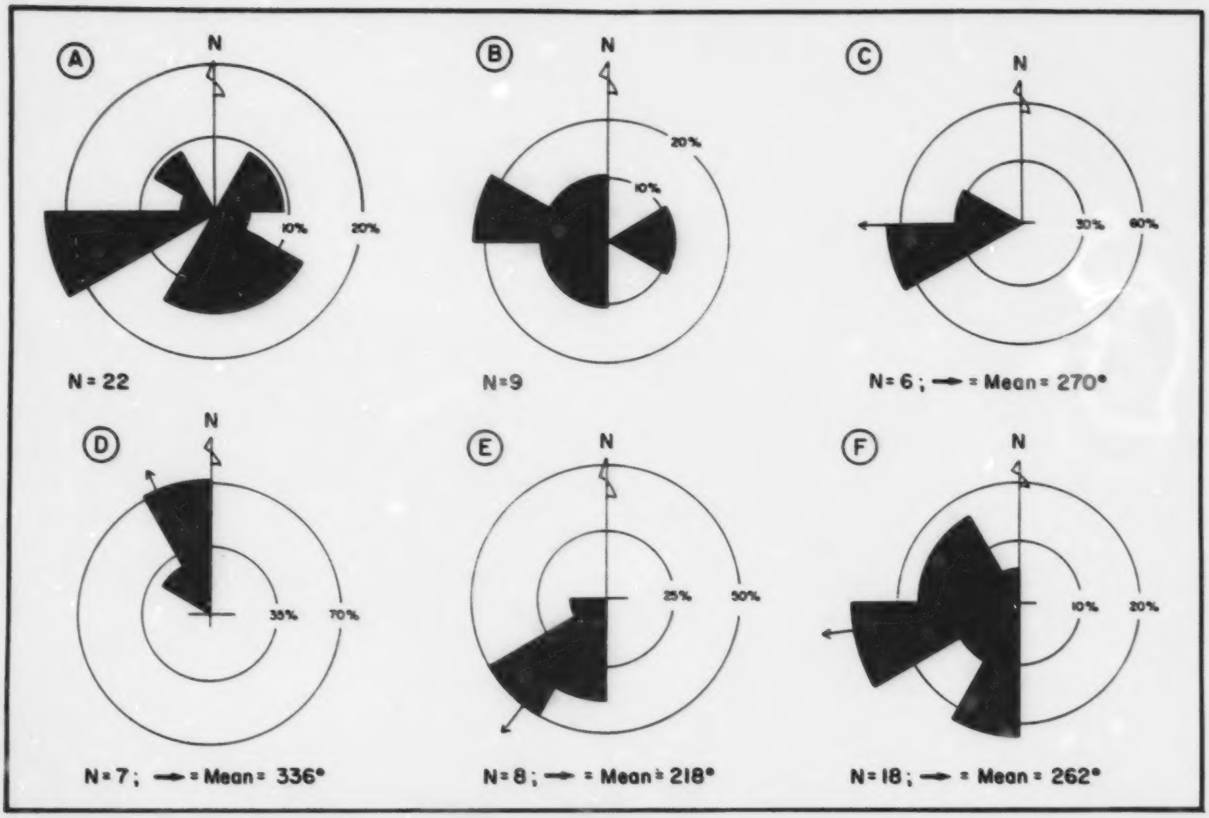

Figure 13: Albert Formation paleocurrent rose diagrams for southeastern Moncton Subbasin. A: Sandstone facies (As), Boyd Creek/Dover area; B: Undivided facies, Boudreau Village/Upper Dorchester area; C: Sandstone facies (As), Frederick Brook; D: Mudstone facies (Am) and kerogenous mudstone facies (Ak), Rosevale/Prosser Brook area; E: Sandstone facies (As), Popple Intervale Brook; F: Conglomerate facies (Ac), Pollett River/Webster Brook area.

(Miall, 1978) are all typical characteristics of braided river deposits (Reineck and Singh, 1980; Mathews, 1974; Williams and Rust, 1969; Bull, 1972; Rust, 1979, 1981; Miall, 1985; McPherson, *et al.*, 1987). The fact that the conglomerates are largely grain-supported and have very little mud matrix also suggests that the deposits are largely water-laid (Williams and Rust, 1969; Bull, 1972; Rust, 1979).

Perhaps not all the coarse conglomerates are water-laid; for example, beds near the Caledonia Uplift in the Prosser Brook and Caledonia Mountain/Boudreau Village fans may represent debris flow deposits (Figure 6c). The beds are invariably thick, outcrops are typically small, and bedding contacts are rarely exposed, such that a definitive statement on the mode of deposition of these rocks cannot be made. Also, a clear indication of transport mechanism is complicated by textural evidence. For instance, the angularity of clasts, the absence of apparent clast orientation, and the absence of internal bedding features suggest a mass flow emplacement mechanism (Bull, 1972; Wasson, 1977), but the mainly clast-supported fabric with little matrix mud speaks against a debris flow mechanism (Bull, 1972). Elsewhere, the significance of mud in debris flows is indicated by the fact that 32 such flows in Tasmania have a mean silt and clay content of 40 per cent (Wasson, 1977). Further work is required on the massive yet mud-deficient Albert conglomerates in the Prosser Brook and Caledonia Mountain/Boudreau Village fans.

The conglomerate facies, as seen in outcrop, contains clasts of boulder and large cobble size near the Caledonia Uplift. In general, clast size in the conglomerate decreases away from the uplift (McCutcheon, 1978; Pickerill, *et al.* 1985). The presence of abundant sand beds within the conglomerate sequences suggests a probable medial or lower fan depositional environment (Bull, 1972; Link and Osborne, 1978; Rust, 1979, p. 16).

Some of the coarse-grained conglomerates and sandstones were assuredly deposited in a lake. This interpretation is supported by the presence of interbeds of fine-grained arenites, mudstones, shales, and limestone. As described above, the arenites, mudstones, shales and limestones provide evidence of having been deposited in a standing body of water (i.e., a lake). Wave ripples in the sandstones, kerogenous (algal) laminations in some mudstones and shales, ostracods and fish scales in shales, and algal stromatolites and oncolites in limestones all imply lacustrine deposition (see lacustrine criteria in Picard and High, 1972). Consequently, the close spatial association of the fine-grained lithotypes with the conglomerates strongly suggests that the conglomerates were deposited adjacent to and, in some cases, within a lake. Thin sections indicate that the conglomerates commonly contain accessory intraformational micritic limestone clasts. Such clasts often show pelletoidal and irregular (swirled) laminae that are interpreted to be of algal origin (Figures 8c and 8d). The source of these clasts is almost certainly Albert lacustrine limestone beds. The limestone clasts in the conglomerates imply either subaqueous erosion and attendant lacustrine deposition, or subaerial erosion of a subjacent intraformational transgressive/regressive carbonate tongue followed by either subaerial or subaqueous deposition.

The siliciclastic, pebble-bearing limestone beds south of Parkindale are without doubt shallow lacustrine deposits. Well rounded quartz and chert pebbles and ostracod-cored algal oncolites set in a spar cement show unequivocal evidence of high-energy nearshore lacustrine deposition. Intraformational and chert-pebble conglomerates have been reported in nearshore facies of the Eocene Lake Uinta of Wyoming and Utah (Picard and High, 1972). In Late Tertiary to Recent Walker Lake, Nevada, carbonate beach rock is described as comprising carbonate-cemented detrital gravels, sands, skeletal material, stromatolites, oncolites, and tufas (Link, *et al.*, 1985).

Therefore, it is concluded that the sediments of the conglomerate facies were deposited mainly by braided streams on alluvial fans and fan deltas. See for example the descriptions of braid deltas and fan deltas by McPherson, *et al.*, 1987), and Soegaard (1990). During large floods coarse-grained sediments were transported across the distal reaches of the fan probably via sheetflood (Hogg, 1982), and were deposited within a contemporaneous lake. A conglomerate-filled channel cut into lacustrine kerogenous shale on Popple Intervale Brook clearly suggests locally rapid erosion and deposition of conglomerate in a nearshore environment.

SANDSTONE FACIES (As)

The sandstone facies consists of grey, fine- to coarse-grained sandstone, with minor interbeds of mudstone, kerogenous mudstone, limestone, and conglomerate.

Distribution and Stratigraphy

The best reference sections of the sandstone facies (As) are: (1) along the upper part of Boyd Creek (Plates 92-34 to 92-36); (2) near Boudreau Village on the east bank of the Petitcodiac River immediately south of Taylor Village Fault; and (3) along Popple Intervale Brook and Mapleton Brook in the Mapleton area. The facies is less well exposed at three other localities: (1) on the east shore of the Petitcodiac River south of Dover; (2) on a small brook draining into the Petitcodiac River just east of the Stoney Creek Gas and Oil Field; and (3) along the upper east tributary of Frederick Brook just north of the Dorchester Fault. The sections at Boyd Creek and Popple Intervale Brook are about 170 m and 250 m thick respectively. Faults at the other sections prohibit an estimate of total thickness, but in all cases, several tens of metres of sandstone are present.

The sandstone facies (As) as shown on Plate 92-36 is not the only sandstone in the Albert Formation in the southeastern Moncton Subbasin; for example, see under MUDSTONE/SANDSTONE FACIES (Ax), pages 48-52. However, it is the thickest and laterally most persistent sandstone sequence in this part of the subbasin, judging from limited outcrop and borehole data. This was first suggested by Foley (1989) from a relogging of well cuttings in the Stoney Creek Gas and Oil Field.

Stratigraphically, sandstone facies (As) lies in the medial part of the Albert Formation, in most places immediately above kerogenous mudstone facies (Ak). This is apparent from Plate 92-36 and the abbreviated logs thereon. The kerogenous mudstone facies (Ak) contains the most organic matter-rich mudstones and shales in the Moncton Subbasin. The superposition of thick sandstones of facies (As) above organic matter-rich source rocks has significant implications with respect to oil and natural gas potential (see under ENERGY RESOURCES, pages 100-103).

Lithology

Sandstone is the dominant lithotype in the sandstone facies (As). It is typically medium grey and weathers grey, buff, or brown. The brown colour is commonly a result of impregnation by bitumen and, where this is the case, freshly broken rock emits a distinct petroliferous odour. Most of the sandstone beds are fine-grained or medium-grained; very fine-grained, and coarse-grained beds occur locally. The sand grains are typically moderately well sorted and characteristically comprise greater than 50 per cent quartz detritus (Figure 14a). This serves to distinguish these sandstones from the quartz-poor sandstones associated with conglomerate facies (Ac) (see page 33 and Figure 9c). In addition to quartz, the sandstones contain feldspar grains and labile clasts. The latter include muscovite, biotite, mica schist, mica phyllite, felsic and mafic volcanics, and accessory chlorite, rutile, hornblende, and opaque minerals. Nodules and disseminations of pyrite are present in some layers. Felsic volcanic fragments and feldspar in many places show extensive alteration to calcite and clay minerals. This is very evident in the sandstones in the section south of Dover.

The sandstones contain less than 15 per cent matrix by volume and accordingly fall into the feldspathic arenite and lithic arenite fields of the sandstone classification of Blackburn, *et al.* (1978). To emphasize the significance of quartz and to distinguish these sandstones from the lithic arenites typically associated with conglomerate facies (Ac), the sandstones are designated quartzose feldspathic arenite and quartzose lithic arenite. The matrix is composed of mainly microspar to sparry calcite, chlorite, and lesser iron oxides, and optically indistinguishable clay mineral(s).

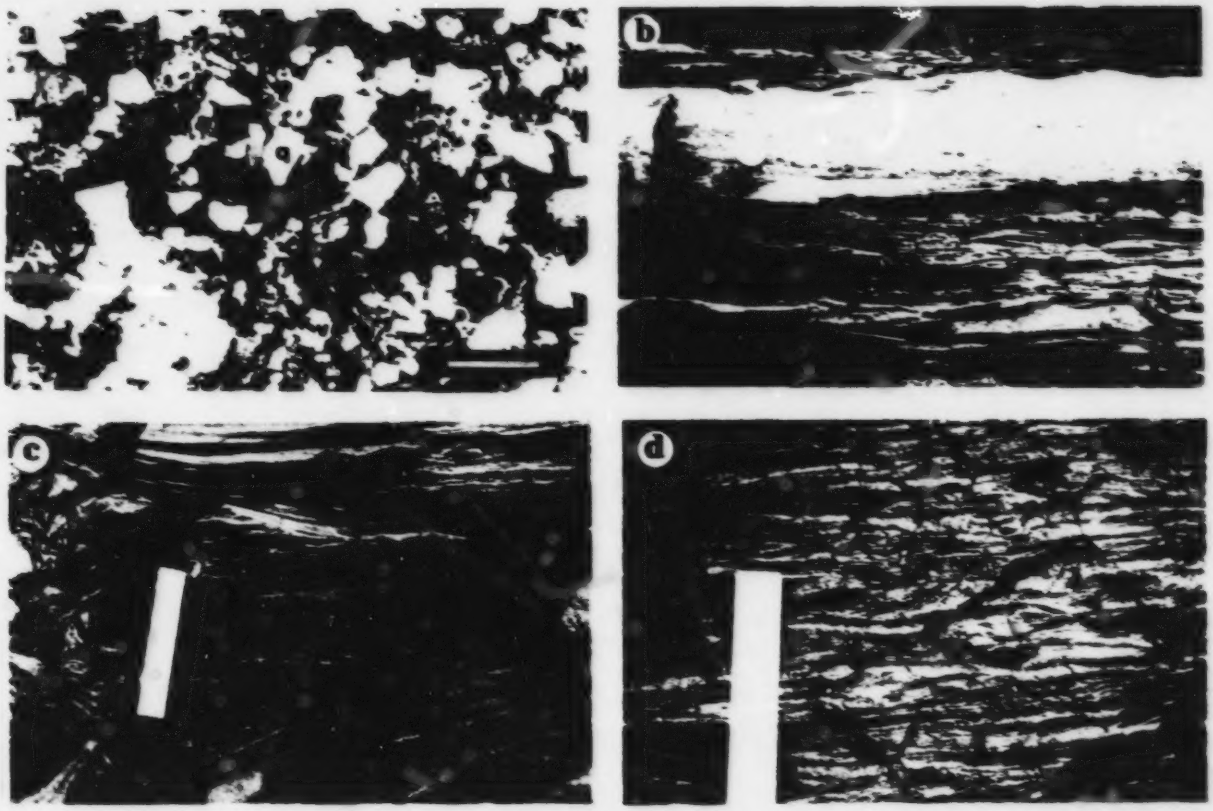

Figure 14: Albert Formation Sandstone Facies (As). (a) Photomicrograph of moderately well sorted, fine medium-grained quartzose lithic arenite showing abundant quartz (q), felsic volcanic grains (v) and minor feldspar (f). Outcrop is on small brook east of the Stoney Creek Gas and Oil Field. Cross-polarized light. Scale bar is 0.5 mm; (b) Very thin to thin beds of sandstone (light grey) with interbeds of calcareous mudstone (dark grey) in the southern part of the Boudreau Village section at the Petitcodiac River. Upper sandstone bed has sharp erosive base, a lower interval of parallel laminae and an upper interval (above coin) of wave-formed ripple laminae. Coin is 19 mm in diameter; (c) Tabular cross-beds in coarse-grained sandstones in the Boudreau Village section. Note how foresets are disturbed below and to left of ruler. Ruler is 17 cm in length; (d) Ripple-drift cross-laminated sandstone in the Boudreau Village section. Transport direction was to the left. Ruler is 32 mm in width.

The sandstone beds range from 1 to 25 cm in thickness (Figures 14b and 14c). Beds are commonly laid down one atop the other forming amalgamated intervals 1 m to several tens of metres thick (Figures 14d and 15a). Individual beds display a variety of sedimentary structures, including: parallel laminations, wavy parallel laminations, wave-formed ripples, interference wave ripples, current-formed ripples, climbing current ripples, cross laminations, and small-scale tabular cross-beds (Figures 14b, 14c, 14d, 15a, 15b, 15c, 15d and 16a). Convolute laminations have been observed in the beds at Dover and Popple Intervale Brook. Parting lineation and load casts have been seen at the base of some beds in the Boyd Creek section. Laminations and ripples of all types are typically defined by dark-coloured laminae less than 1 mm in thickness alternating with light-coloured laminae of greater thickness. The dark-coloured laminations are enriched in biotite, muscovite, and opaques, while the light-coloured

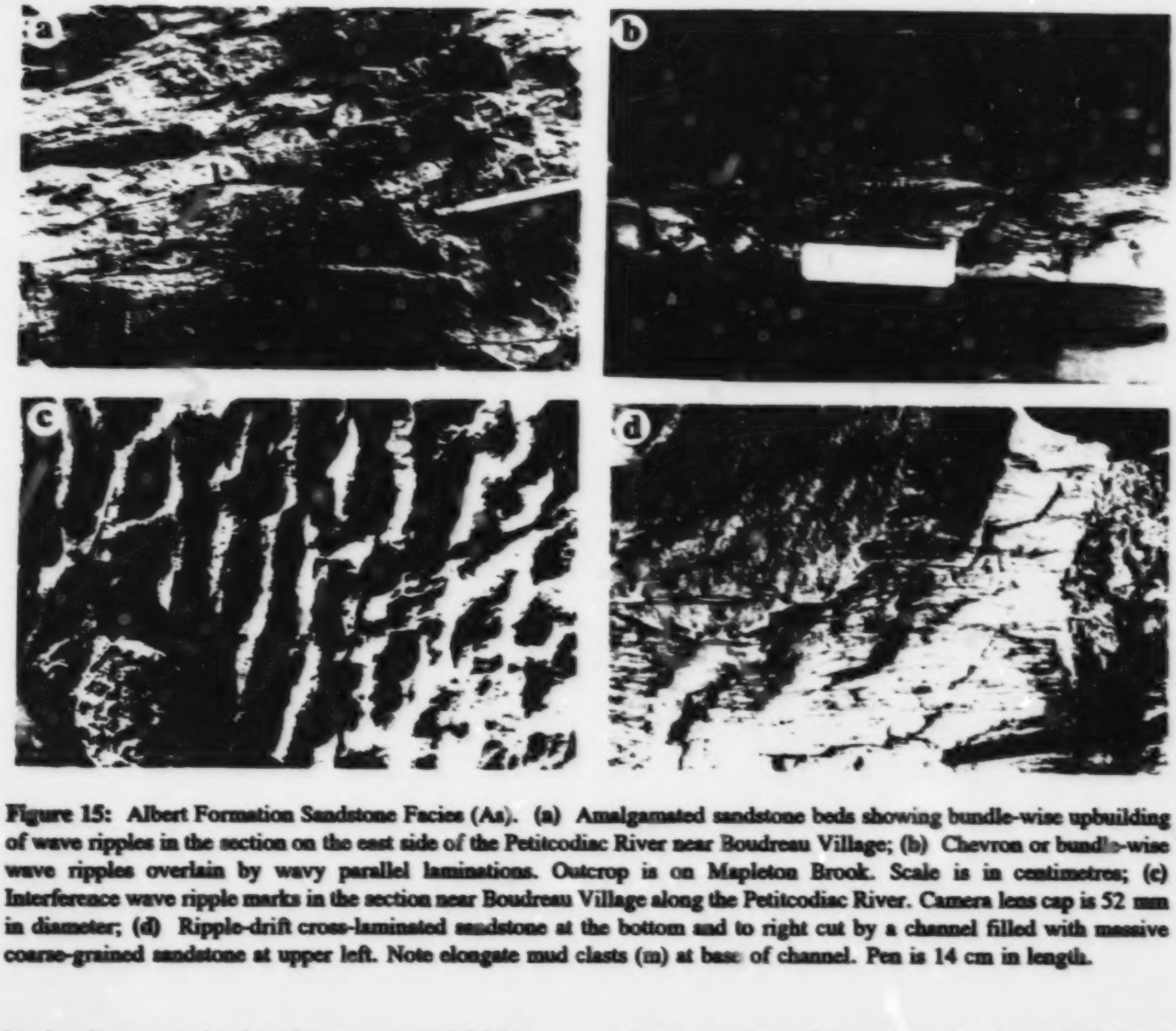

Figure 15: Albert Formation Sandstone Facies (As). (a) Amalgamated sandstone beds showing bundle-wise upbuilding of wave ripples in the section on the east side of the Petitcodiac River near Boudreau Village; (b) Chevron or bundle-wise wave ripples overlain by wavy parallel laminations. Outcrop is on Mapleton Brook. Scale is in centimetres; (c) Interference wave ripple marks in the section near Boudreau Village along the Petitcodiac River. Camera lens cap is 52 mm in diameter; (d) Ripple-drift cross-laminated sandstone at the bottom and to right cut by a channel filled with massive coarse-grained sandstone at upper left. Note elongate mud clasts (m) at base of channel. Pen is 14 cm in length.

laminations contain abundant quartz and feldspar. Where the rock splits along bedding, a sheen due to the presence of bedding-parallel mica is evident. This is a distinctive characteristic of Albert quartzose arenites. Plant fragments are also locally abundant on bedding surfaces.

There are several recurring bedforms. Many beds comprise a parallel-laminated lower part with a wave ripple-laminated or current ripple cross-laminated upper part (Figure 14b). Some beds in the Boudreau Village section grade from coarse-grained and tabular cross-bedded near the base to finer grained and parallel-laminated near the top (Figure 14c). Climbing ripple-drift cross laminations (Types A and B of Jopling and Walker, 1968) are present in the beds at Boudreau Village and Frederick Brook (Figure 14d). The ripple drift beds at Boudreau Village are locally cut by channels up to 20 cm deep, which are filled with massive coarse-grained sandstone (Figure 15d). Sand beds in the section at Popple Intervale Brook have very small scale tabular cross-beds 5 to 10 cm thick with interbeds containing climbing ripples (Figure 16a). Several sandstone beds in the section along Boyd

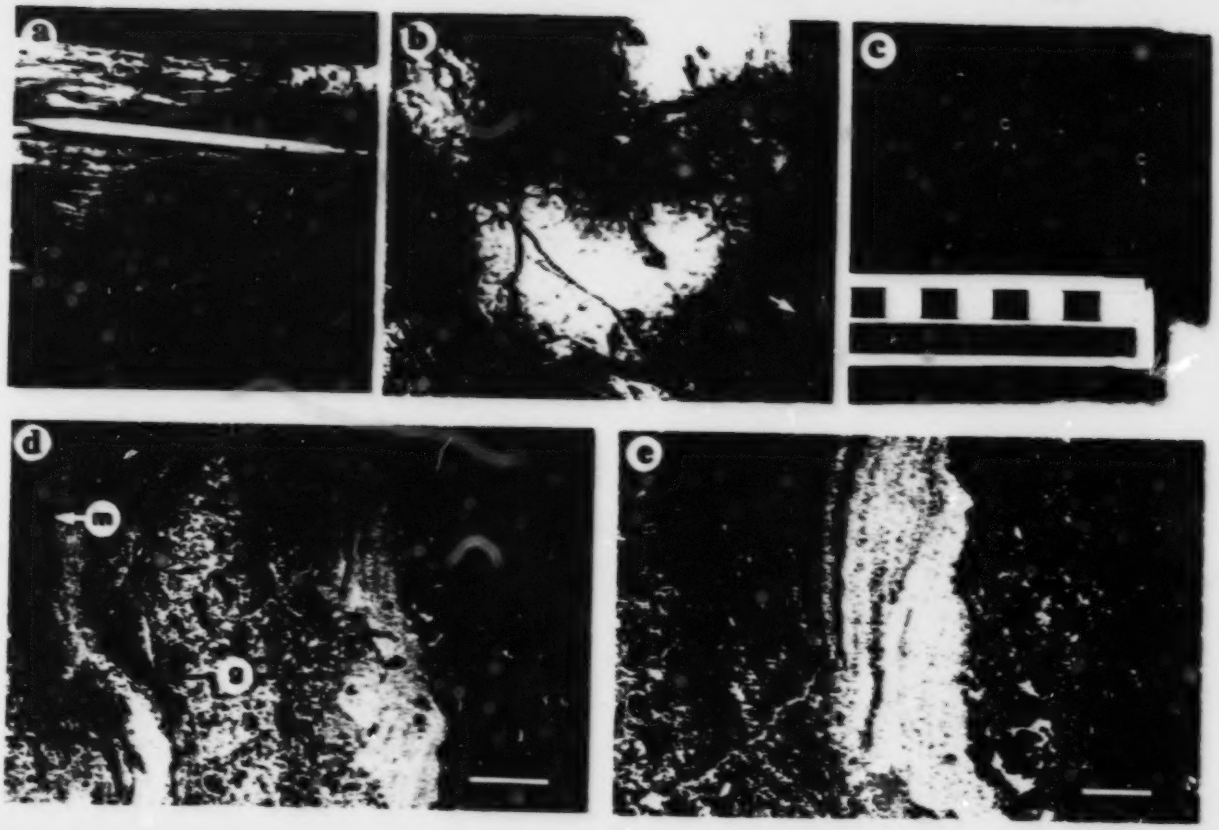

Figure 16: Albert Formation Sandstone Facies (As). (a) Quartzose lithic arenite on Popple Intervale Brook showing parallel-laminated lower interval (indistinct) and current ripple-laminated upper interval. Current direction to the left, that is, to the southwest; (b) Mudstone bed with mudcracks (arrows) in sandstone interval on Popple Intervale Brook; (c) Algal-laminated limestone with dark grey micritic clasts (c) in a lighter grey microsparry cement. Sample is from Mapleton Brook. Scale in centimetres. See Figures 16d and 16e for photomicrographs of laminae; (d) Photomicrograph of interlaminated micritic mudstone (m), intraclast grainstone (g), and cross-laminated siliciclastic sandstone (s) at Mapleton Brook. Note erosive lower contacts of sandstone and some grainstone layers. Note also grading in grainstone laminae and a fracture cleavage offsetting the laminae, thereby complicating the primary structures. Plane-polarized light. Scale bar is 5 mm; (e) Photomicrographic detail of graded grainstone and cross-laminated sandstone shown in Figure 16d. Plane-polarized light. Scale bar is 2 mm.

Creek are graded from medium-grained at the base to very fine-grained at the top. The graded beds typically contain angular intraclasts (rip-up clasts) of dark grey mudstone near their base suggesting rapid local erosion and deposition. Such graded beds are interstratified with sands showing wave ripple laminations.

The sandstone facies contains minor thin beds of dark grey mudstone and/or kerogenous mudstone at Popple Intervale Brook, Frederick Brook, Boyd Creek, Boudreau Village and Dover (Figures 14b and 16b). The mudstone strata range in thickness from 1 cm up to intervals 5 m thick. Mudstones at Mapleton and Boudreau Village show mudcracks (Figure 16b); those at Mapleton also display irregular diagenetic limestone nodules. The mudstone beds are lithologically indistinguishable from the beds described below under MUDSTONE

FACIES (Am), pages 52-56.

The sandstone sections exposed along Mapleton Brook, Frederick Brook and near Boudreau Village contain thin beds of limestone. In the Mapleton section the limestone beds comprise micritic mudstone and fine- to coarse-grained grainstones. The mudstone beds have two types of laminae: (1) subtle parallel micrite laminae of probable algal origin, and (2) wackestone or grainstone laminae that are similar to grainstone interbeds in the section. The grainstone interbeds are characterized by laminae of micritic mudstone (Figure 16d) and parallel to cross laminae of siliciclastic sandstone (Figure 16e). The grainstones consist of poorly sorted micrite intraclasts up to 5 mm in length, and variable quantities of silt and sand-size quartz, feldspar and mica set in a spar cement (Figures 16c and 16d). Some grainstone layers display erosional bases and coarse-tail grading of micrite intraclasts (Figures 16d and 16e) suggesting deposition possibly from decelerating storm currents.

The limestone strata at Frederick Brook occur at three stratigraphic positions within the sandstone section: at the base, 100 m above the base, and 190 m above the base. All the limestone beds range from 2 to 20 cm thick and occur over intervals up to 3 m in thickness. The limestone beds are typically interbedded with mudstone or kerogenous mudstone (Figure 17a). The limestone beds comprise light grey, buff-weathering micritic mudstone and siliciclastic-rich carbonate grainstones. The mudstone beds consist of subtle micrite-rich and microspar-rich parallel laminae (Figure 17b). The micrite occurs in three morphological forms: (1) as diffuse peloids, (2) as irregular "patches" and (3) as envelopes around blade- to wave-shaped bodies that have a central core of microspar or spar (Figure 17c). The micrite probably represents algal remains; the blade-like structures may represent the remains of phylloid algae. Detritus in the carbonate grainstone beds consist of 20 per cent fine to very coarse sand grains of quartz, chert, and shale, 30 per cent quartz silt, and accessory oncolites all set in a calcite cement. The oncolites range in size from 1 to 6 mm along their longest dimension. Some are spherical, but many are elliptical or sausage-shaped and comprise layers of calcite enveloping a central sand grain.

A laminated stromatolite mound in the limestone interval at the base of the sandstone section at Frederick Brook (Figure 17d) consists of interlaminated brown micrite and light grey microspar. The brown colour of the micrite may be due to finely dispersed kerogen. Immediately below many of the micrite laminae in the mound are narrow layers of fibrous calcite with the long axes of crystals oriented perpendicular to bedding (Figure 18a). The calcite is interpreted as a void-filling mineral possibly following the decay of organic matter (algae?). Evidence that the calcite is filling a void is also shown by collapse of the overlying micrite laminae, thus giving rise to micrograbens floored by the down-dropped micrite. The micrograbens are subsequently filled by carbonate sediment and consequently the laminae that lie above the micrite laminae show no sign of disturbance (Figure 18a).

The sandstone section on the east side of the Petitcodiac River near Boudreau Village also contains a few interbeds of carbonate mudstone and siliciclastic-rich carbonate grainstone (Figure 18b). The limestone beds there differ from those at Frederick Brook in several ways; for example, many of the carbonate mudstone beds at Boudreau Village show well preserved mudcracks (Figure 18c) and some display rain prints (Figure 18d). Coarse-grained grainstone fills the cracks of some of the desiccated mud beds. Beds of grainstone at Boudreau Village are up to 12 cm thick and typically pinch out over a few metres. The grainstone layers invariably contain siliciclastic detritus and carbonate mudstone intra-

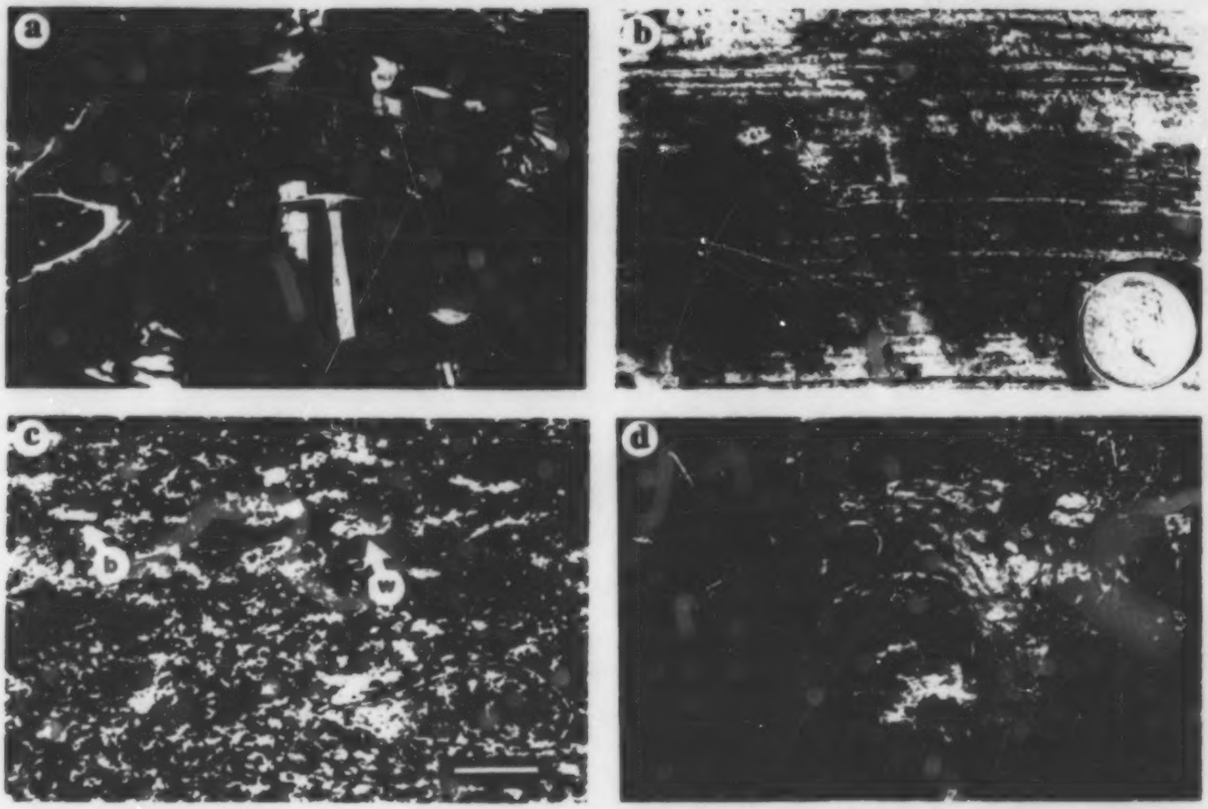

Figure 17: Albert Formation Sandstone Facies (As). (a) Interbedded oncolitic grainstone, carbonate mudstone, and kerogenous mudstone in sandstone facies at Frederick Brook; (b) Parallel-laminated carbonate mudstone beds showing micrite-rich and microspar-rich laminae. Outcrop is at base of sandstone interval on Frederick Brook. Coin is 19 mm in diameter; (c) Photomicrograph of morphological forms of micrite in carbonate mudstone at Frederick Brook. Note irregular to elliptical patch (possibly telalginite (t)), and envelopes around blade-shaped (b) and wave-shaped (w) bodies. Unpolarized light. Scale bar is 0.5 mm; (d) Algal laminated stromatolitic limestone mound at base of sandstone facies at Frederick Brook. See Figure 18a for details. Camera lens cap is 52 mm in diameter.

clasts, the latter ranging up to 2 cm in length. Those grainstone beds containing abundant angular mud chips are probably the result of erosion of intensely desiccated mudstone interbeds.

The sandstone facies in places contains minor interbeds of conglomerate. These beds have not been seen in surface sections, but are present in the subsurface at Irving/Chevron Lee Brook No. 1, Imperial Berryton No. 1, and N.B.G.O. No. 100 wells (borehole Nos. 1, 5, and 11 respectively, Plates 92-34 to 92-36). Ditch cuttings from Lee Brook No. 1 indicate that the conglomerate is poorly sorted and polymictic. The clasts range from very coarse sand to pebbles and comprise quartz, quartzite, feldspar, felsic volcanic rock, metasiltstone, and accessory limestone in a muddy sand matrix. The clast composition and texture of the conglomerate in the cuttings suggest the beds are the same as those in conglomerate facies (Ac) exposed 2 km east of the Lee Brook well along the Pollett River (Plates 92-34 and 92-36).

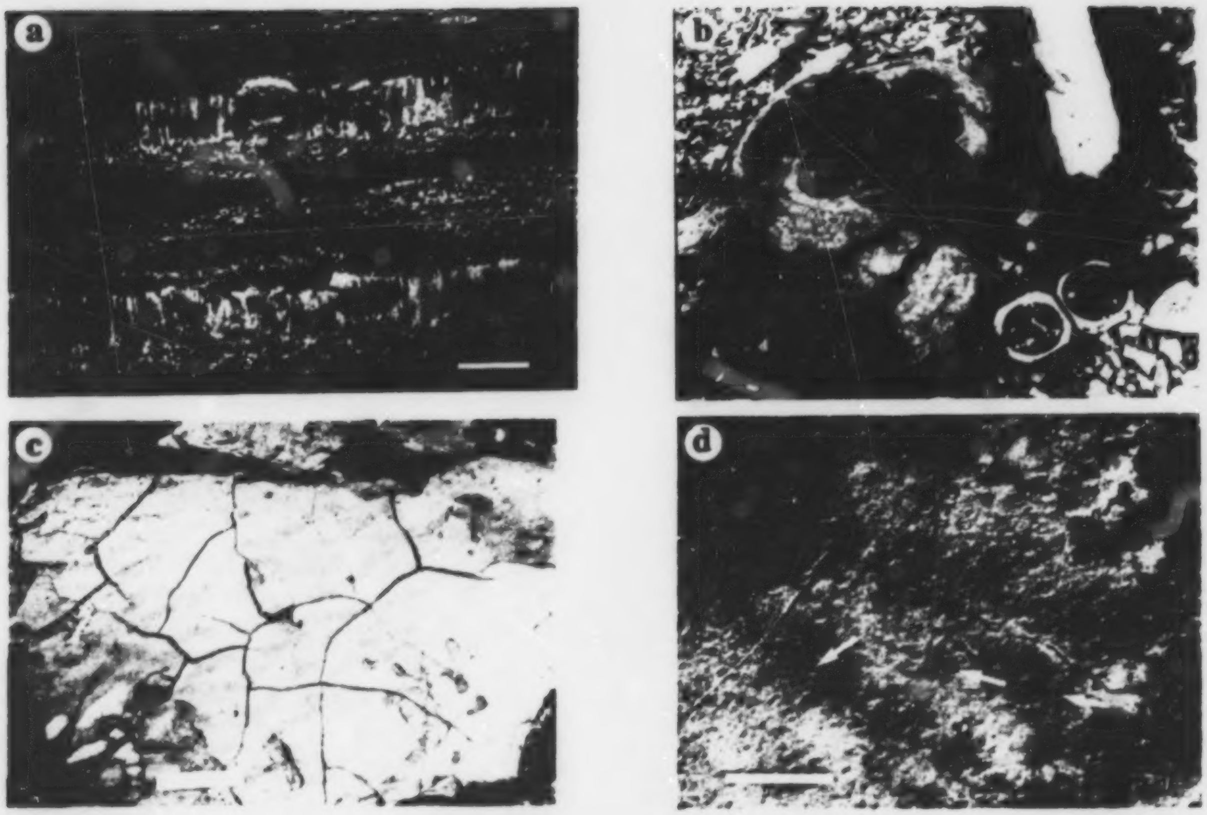

Figure 18: Albert Formation Sandstone Facies (As). (a) Photomicrograph of interlaminated micrite (dark grey) and microspar (light grey) in part of a stromatolite mound. Fibrous calcite void-fillings occur below micrite layers. Note the collapsed micrite layers (arrows) defining the floors of micrograbens. Sample is from the mound shown in Figure 17d. Unpolarized light. Scale bar is 3 mm; (b) Isoclinally folded fine-grained grainstone with parallel laminae of algal(?) micrite. Limestone bed occurs within sandstones (seen at upper right in photo) in the Boudreau Village section along the Petitcodiac River; (c) Desiccation cracks in carbonate mudstone at the Boudreau Village section. Ruler is 17 cm in length; (d) Rain prints (arrows) in carbonate mudstone at the Boudreau section. Scale bar is 2 cm.

Paleocurrents

Current transport determinations for sandstone facies (As) in the Boyd Creek/Dover area, Frederick Brook section and Popple Intervale Brook section are summarized in Figures 13A, 13C and 13E, respectively. Paleoflow indicators in the Boyd Creek and Dover areas (Figure 13A) are exclusively cross laminations except for one tabular cross-bed seen on the small brook near the Stoney Creek Gas and Oil Field. The Boyd Creek/Dover data indicate a wide range of paleoflows with predominant transport towards south of west and south. The absence of a clear maximum suggests that the cross laminations were perhaps generated by a variably directed current or by several types of currents. Walker (1984) describes four types of currents that are active on modern marine shelves. Of these, only meteorological (storm) currents and density (turbidity) currents could be generated in a nonmarine shallow-water environment like that envisaged for paleolake Albert. The presence of graded beds, some with basal mudstone intraclasts in the Boyd Creek section, suggests that storm-generated currents were common in this area. Wave-formed ripples in interbedded strata further suggest deposition above fairweather wave base.

The sandstones at Frederick Brook are cross-laminated. Limited current measurements (N=6) give a unimodal westerly transport direction (Figure 13C). The absence of wave ripples or rip-up clasts in the sands there may imply deposition in somewhat deeper water than at Boyd Creek and Dover.

In the southwestern part of the map area at Popple Intervale Brook, cross laminations indicate a southwest-directed paleoflow with a mean of 218° (Figure 13E). Although the data provide a convincing unimodal distribution, it is not clear what type of current generated the cross laminae or if the indicated transport direction can be taken as a reliable indicator of a southwest-dipping paleoslope. For example, the sandstone beds at Popple Intervale Brook and also to the southwest at Mapleton Brook display unequivocal wave-generated ripples. This demonstrates deposition above fairweather wave base and thereby implies that the cross laminae at Popple Intervale Brook may have resulted from wave-generated currents. Such wave-generated currents could have been directed parallel or at an oblique angle to the paleo-shoreline. Paleochannels in conglomerate facies (Ac) along the Pollett River and Webster Brook (see above under CONGLOMERATE FACIES (Ac), page 37) strongly suggest a northwest-directed paleoslope in this part of the Moncton Subbasin. If this is in fact the case, then the unidirectional cross laminations at Popple Intervale Brook most likely resulted from longshore currents.

Depositional Environments

The sandstone facies (As) is believed to have been deposited in a marginal lacustrine environment. Because the facies shows evidence of local subaerial and widespread subaqueous deposition, it is implied that sedimentation took place near a lacustrine strand.

The facts that the sandstones lie within mudstones and kerogenous mudstones of undoubted lacustrine origin (see below under MUDSTONE/SANDSTONE FACIES (Ax), pages 48-52, and KEROGENOUS MUDSTONE FACIES (Ak), pages 63-78, for further details), and that the sandstones commonly display wave ripples, strongly imply deposition mainly above storm wave base. Further evidence of shallow lacustrine sedimentation is provided by intraformational mudstone rip-up clasts in sandstones at Boyd Creek and Popple Intervale Brook, and in limestones at Mapleton Brook and Boudreau Village. Such rip-up clasts are a common feature of shoreface storm deposits in shallow marine environments (Ball, 1971; Brenner and Davies, 1973; Kumar and Sanders, 1976, 1978) and there is no reason to doubt a similar origin in shallow lacustrine sands. Paleocurrent data, particularly in the Boyd Creek/Dover area, are consistent with variably directed storm currents.

The presence of algal-laminated limestone and oncolitic limestone within sandstone facies (As) also supports a shallow lacustrine setting (Osborne, *et al.*, 1982). For example, algal oncolites typically occur in marginal lake environments between the high-energy shoreline and deeper water where carbonate production is less. This is seen in modern Lake Constance (Reading, 1978), and in Late Tertiary to Recent Walker Lake, Nevada (Link, *et al.*, 1985).

The water level of a lake is much more variable than that of the sea (Picard and High, 1972; Link, *et al.*, 1985) and is subject to both climatic and tectonic variables. Such variables as rainfall, inflow, discharge, and evaporation have a fundamental control on water level (Hardie, *et al.*, 1978). Tectonic instability with its resulting control on subsidence rates is, however, considered to be the primary control on lake water level in rift and pull-apart basins (Blair, 1987; Blair and Bilodeau, 1988; Martel, 1990). Consequently, relatively rapid transgressions and regressions of a lake in a syntectonically active basin, such as that envisaged for the Moncton Subbasin, are to be expected. This has been admirably demonstrated for example in Late Tertiary to Recent lacustrine strata of the strike-slip Walker Lake Basin of Nevada (Link, *et al.*, 1985). Evidence that transgressions and regressions were commonplace in paleolake Albert is shown by mudstones displaying limestone caliche nodules and mudcracks in close association with sandstone showing wave ripples and storm layers. Similar fluctuations in lake levels have been documented in correlative Tournaisian lacustrine deposits of the Horton Bluff Formation of Nova Scotia (Hesse and Reading, 1978).

The trace fossil assemblage *Cruziana problematica, Rusophycus problematicum and Palaeophycus sp.*, identified in sandstone facies (As) in the section near Boudreau Village (Pickerill, *et al.*, 1985), further corroborates a subaqueous depositional setting. Frey and Pemberton (1984) assign the Cruziana ichnofacies to sublittoral substrates.

Southwest of the map area along Cedar Camp Brook near Waterford (Plate 92-33), Albert sandstone beds have hummocky cross-stratification attesting to the widespread association of storm activity with sandstone facies (As) (St. Peter, 1989).

The sandstones along the shoreline of Walker Lake, Nevada, are the best described modern analogue for the Albert sandstones. Link, *et al.* (1985) described the nearshore sandstones of Walker Lake as comprising submerged sandflats of fine- to medium-grained, rippled sands on the lower part of alluvial fans and fan deltas. The sands occur to a water depth of 26 m. On one side of the lake the sands have been reworked into sheet sands by waves and shoreline processes. The sands in Walker Lake are chiefly derived from fan deltas and river deltas and are subsequently winnowed by waves and longshore processes.

In addition to submerged sandflats, the shoreline deposits of Walker Lake include gravel ridges and sand ridges and spits that are formed by longshore transport. Sand bodies of this type are commonly bound on the landward side by mudflats and on the lakeside by rippled sandflats (Link, *et al.*, 1985, figs. 12A, C, and D). The sandflats pass lakeward into carbonate and muds rich in organic matter.

Comparisons of the Albert Formation sandstones with the Walker Lake sandstones are obvious. The sandstones in the Popple Intervale Brook, Mapleton Brook, and Boudreau Village areas are associated with coarse alluvial fan and fan delta deposits (see above under CONGLOMERATE FACIES (Ac), pages 24-39 , and Plate 92-36). Paleocurrents at Popple Intervale Brook suggest reworking by longshore currents. The sandstones in the Boyd Creek/Dover area occur within mudflat and organic matter-rich lacustrine mudstones and shales (Howie, 1968; Pickerill, *et al.*, 1985; Foley, 1989). Wave ripples and variably directed current indicators in this area suggest reworking of detritus on submerged sandflats and/or sand ridges. Further evidence of the depositional environment of the sandstones in the Dover and Stoney Creek areas is given below under Mudstone/Sandstone Facies (Ax).

MUDSTONE/SANDSTONE FACIES (Ax)

The mudstone/sandstone facies (Ax) comprises abundant grey mudstone and brown kerogenous mudstone, subordinate feldspathic and lithic sandstone, and minor conglomerate, kerogenous shale, nodular limestone, and oncolitic limestone.

Distribution and Stratigraphy

The best exposures of this facies are seen along three streams east of the Petitcodiac River: Downing Creek, Boyd Creek, and an unnamed creek about 600 m northeast of Boudreau Village (cf., Plates 92-34 and 92-36). Beds on the unnamed brook strike southwesterly and they are exposed on the east bank of the Petitcodiac River in juxtaposition with conglomerate facies (Ac) along the Boudreau Fault. In the western part of the map area, the lithofacies crops out northwest of Elgin on Lee Brook. Other small exposures occur east of the Mapleton Fault along Mapleton Brook.

The mudstone/sandstone facies (Ax) is well represented in the subsurface at the Stoney Creek Gas and Oil Field, where intervals of sandstone up to and locally greater than 30 m thick (Howie, 1968) occur within a sequence dominated by mudstone, kerogenous mudstone, shale and kerogenous shale (Greiner, 1962; Howie, 1968; Pickerill,*et al.*, 1985; Foley, 1989). The lithologic log of Irving/Chevron Stoney Creek No. 1 well (borehole No. 17, Plate 92-36) is a simplification of the scale of mudstone and sandstone interstratification within the oil and gas field (see Foley, 1989). Several hundred metres of mudstones and shales with lesser interbedded sandstones are also seen in Shell Belliveau No. 1 well (borehole No. 30, Plate 92-36).

In the subsurface between Elgin and Petitcodiac (Plate 92-36), the upper part of the Albert Formation is thought to comprise mostly mudstone/sandstone facies (Ax). This is based on three lines of evidence: (1) interbedded mudstone and sandstone occur in the upper Albert section at Irving/Chevron Lee Brook No. 1 well (borehole No. 1, Plate 92-36); (2) interbedded mudstone, shale, and sandstone are exposed north of Petitcodiac near Fawcett (Plate 92-33) (see Plates 42-44, 47, and 48A in Carter, 1985); and (3) the seismic reflection configuration for Albert strata in this part of the subbasin implies an inhomogeneous (interbedded) lithofacies (see Plates 92-46 and 92-47, and seismic Facies Aᴀ, page 84).

Lithology

The mudstone/sandstone facies (Ax) does not have a characteristic or distinguishing lithotype. The lithotypes in this facies are indistinguishable from equivalent lithotypes in the other Albert lithofacies. For example, the grey mudstone, kerogenous mudstone, and nodular limestone of this facies are analogous to grey mudstone, kerogenous mudstone and nodular limestone of mudstone facies (Am); feldspathic arenite, lithic arenite, and oncolitic limestone of this facies are the same as sandstones and oncolitic limestone in sandstone facies (As); and the minor beds of coarse lithic sandstone and polymictic conglomerate are no different from similarly described lithotypes in conglomerate facies (Ac).

Although the mudstone/sandstone facies contains no unique lithotype, it is distinguished from the five other Albert lithofacies by the following criteria:

> (1) it contains no red mudstone and thereby may be separated from mudstone facies (Am),
>
> (2) it contains appreciably more coarse clastic strata than mudstone facies (Am) (Figures 19a and 19b),
>
> (3) the sandstone intervals in the facies, although significant, are not sufficiently thick or laterally continuous to separate at 1:10 000 or smaller map scales. There-

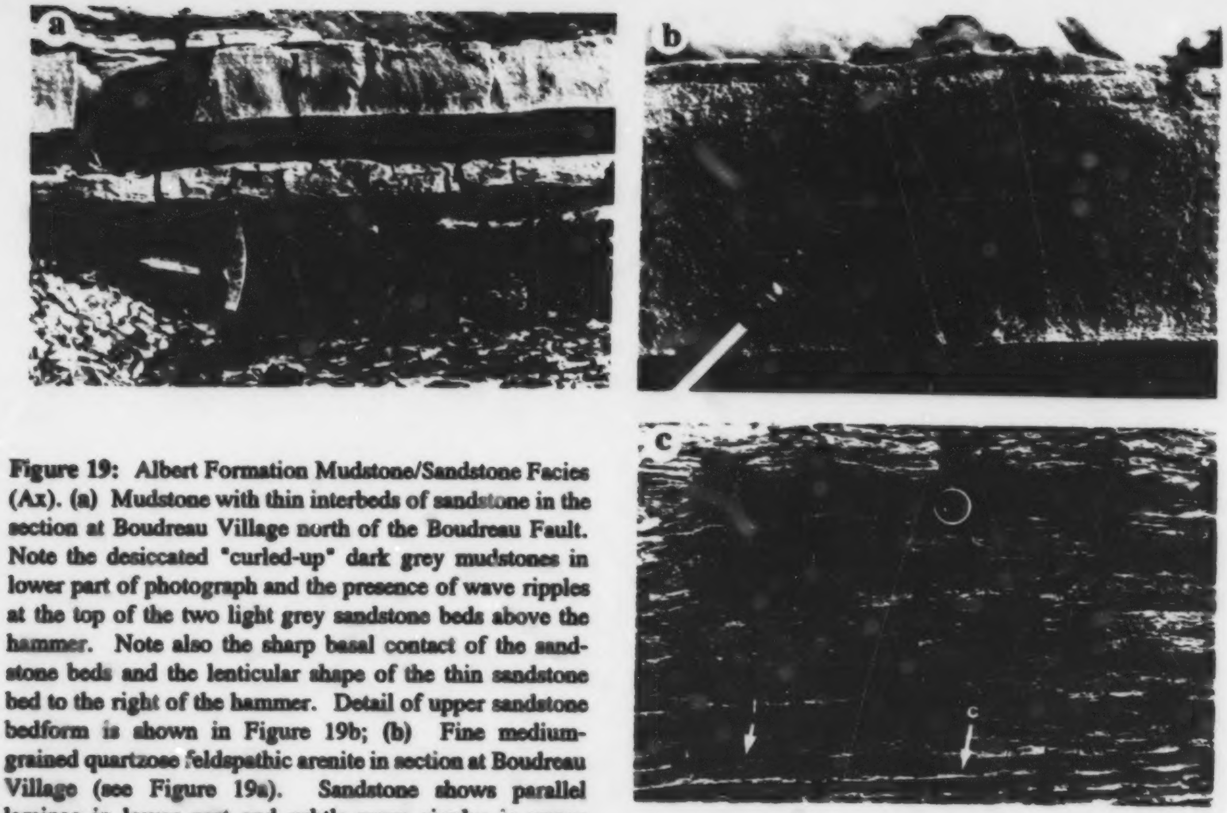

Figure 19: Albert Formation Mudstone/Sandstone Facies (Ax). (a) Mudstone with thin interbeds of sandstone in the section at Boudreau Village north of the Boudreau Fault. Note the desiccated "curled-up" dark grey mudstones in lower part of photograph and the presence of wave ripples at the top of the two light grey sandstone beds above the hammer. Note also the sharp basal contact of the sandstone beds and the lenticular shape of the thin sandstone bed to the right of the hammer. Detail of upper sandstone bedform is shown in Figure 19b; (b) Fine medium-grained quartzose feldspathic arenite in section at Boudreau Village (see Figure 19a). Sandstone shows parallel laminae in lower part and subtle wave ripples in upper part, suggesting reworking of top of bed in shallow lake environment; (c) Mudstone beds at the Boudreau Village section showing profile of curled-up mud cracks and continuous (c) to lenticular (l) fine-grained sandstone laminae.

fore, the sandstones, although the same as the sandstones of sandstone facies (As), are not mappably separable as such,

(4) it contains no thick organic matter-rich kerogenous shales, which serves to distinguish it from kerogenous mudstone facies (Ak), and

(5) it contains no bedded glauberite or halite and accordingly is easily separable from evaporite facies (Ae).

The mudstone/sandstone facies (Ax) is, therefore, a regionally distinctive unit comprising a "mixture" of mudstone (Am), sandstones (As), and conglomerate (Ac) lithofacies, but in which the lithotypes are interbedded on a mappably inseparable scale. For this reason, the mudstone/sandstone facies (Ax) is commonly seen to grade both vertically and laterally into the other clastic Albert lithofacies (Plate 92-36).

Depositional Environment

The mudstone/sandstone (Ax) facies in the southeastern Moncton Subbasin is interpreted as a nearshore and "shallow" lacustrine sequence. As described below, under Mudstone Facies (Am), the word "shallow" is used only in a relative sense to imply water a few metres or perhaps tens of metres deep, but not deep enough to result in the lower energy and highly anoxic conditions that are implied for kerogenous mudstone facies (Ak) (see pages 77-78).

A relatively low energy lacustrine setting for the mudstone/sandstone (Ax) facies is indicated by the abundance of grey mudstones, silty parallel-laminated mudstones and brown calcareous and dolomitic kerogenous mudstones (Figure 19c). The mudstones and, particularly, the kerogenous mudstones in many places contain rhomboid-shaped black vitreous scales of fresh water palaeoniscid fish (Lambe, 1909; Greiner, 1974, 1977). The disarticulation of fish implies higher energy conditions in this environment than in the deep lacustrine setting of kerogenous mudstone facies (Ak) (see page 77). Mudstone beds on the north side of the Boudreau Fault on the east bank of the Petitcodiac River show well preserved mudcracks attesting to periodic desiccation possibly as a result of lower lake water level (Figure 19c). Thin interbeds of fine- to medium-grained feldspathic arenites in the same section display unmistakable wave-formed ripples (Figure 19b) like the knitted and chevron-upbuilding morphologies described by de Raaf, *et al.*(1977). Deposition above wave base for the sandstones is clearly indicated.

The mudstone/sandstone (Ax) facies along Mapleton Brook east of Elgin contains local interbeds of conglomerate and gritty sandstone. The coarse beds there are interpreted as tongues of high energy braid delta origin that infrequently encroached upon this otherwise quiet low energy muddy environment.

The presence of preserved organic matter in the form of kerogen laminae within kerogenous mudstones and locally within beds of kerogen-rich shale indicates that the lake was stratified and that even in relatively shallow water, bottom conditions were occasionally anoxic (Greiner, 1962, p. 232; Smith, 1985; Smith, *et al.*, 1991). Organic petrology and organic geochemical studies have shown the kerogen to be mainly Type I organic matter and therefore largely derived from fresh-water algal precursors (King, 1963; Altebaeumer, 1985; Kalkreuth and Macauley, 1984; Macauley and Ball, 1987; Smith, 1985; Smith and Gibling, 1987; Smith, *et al.*, 1991). See below under KEROGENOUS MUDSTONE FACIES (Ak), pages 77-78, for further discussion of environmental implications regarding organic matter.

The fine- to medium-grained sandstone intervals within the mudstone/sandstone facies (Ax) at the Stoney Creek Gas and Oilfield (cf., Plates 92-35 and 92-36) have been ascribed a deltaic origin by Greiner (1962, p. 234) and Howie (1968) or a fluvial-deltaic origin by Pickerill, *et al.* (1985, p. 29-30). The most recent wells drilled in the field — Irving/ Chevron Stoney Creek No. 1, and Irving/Chevron East Stoney Creek No. 1 wells (borehole Nos. 17 and 18 respectively, Plates 92-35 and 92-36) — show that there are no coarsening-upward cycles, such as those expected for a prograding river-dominated or wave-dominated delta (Miall, 1979, 1984; Friedman and Sanders, 1978). Lithologic logs of ditch cuttings from the Irving/ Chevron Stoney Creek No. 1 well indicate two types of cycles: (1) fining-upward; and (2) coarsening-upward/fining-upward. Fining-upward cycles are best represented in the interval between 1 017 m and 1 075 m below surface. They range from 1.5 m to 5 m in thickness and grade from medium or coarse sand at the base to very fine-grained sand and silt at the top. A 15 m thick fining-upward cycle at 1 060 to 1 075 m begins with pebble conglomerate at the base and grades to fine-grained quartzose arenite at the top. Fining-upward cycles of similar scale have been described by Pickerill, *et al.* (1985) from sandstone facies (As) in the section at Boudreau Village south of the Taylor Village Fault (Plates 92-34 and 92-36). Good examples of cycles of the second type, coarsening-upward/fining-upward, occur in the Stoney

Creek No. 1 well between 585 m and 698 m. These cycles vary from 2 m to 10 m in thickness and range from very fine-grained or fine-grained sand at the base and top to medium- or rarely coarse-grained in the medial part of the cycles.

The absence of solitary coarsening-upward cycles suggests that the Stoney Creek sandstones are not river-dominated or wave-dominated deltas in the classical sense (Miall, 1979, 1984). Also, the absence of typical delta topset beds (coarse sandstones and conglomerates, oxidized redbed mudstones, paleosols, or back swamp marsh deposits) argue against a deltaic origin (Miall, 1984).

Outcrops of sandstones along strike from Stoney Creek on the east side of the Petitcodiac River clearly indicate that the sandstones are not fluvial deposits; there are no channel lag conglomerates, no definitive trough or planar cross-bedded channel sandstones or overbank oxidized mudstones, and no fining-upward sequences, as one would expect in either meandering or braided fluvial sequences (Rust, 1979; Rust and Koster, 1984; Miall, 1978; Walker and Cant, 1984).

Clearly, the facts that the sandstones lie within mudstones of undoubted lacustrine origin, contain wave-formed ripples, and contain cross laminations showing no obvious paleocurrent maxima (Figure 13A), strongly imply the sandstones are within lake beds deposited mainly above storm wave base. In this regard, the fining-upward and coarsening-upward/fining-upward sequences seen in well cuttings at Stoney Creek are interpreted as transgressive (i.e., waning energy) and regressive/transgressive cycles, respectively.

MUDSTONE FACIES (Am)

The mudstone facies comprises grey and lesser red mudstone and shale with minor interbeds of sandstone, conglomerate, kerogenous mudstone, kerogenous shale, and nodular limestone.

Distribution and Stratigraphy

The best exposures of grey mudstone are along Popple Intervale Brook at Mapleton where about 350 m of section is exposed between the Pollett River Fault in the south and the overlying beds of sandstone 400 m north of Highway 895 (Plates 92-34 and 92-36).

In the northern part of the map area, and immediately overlying Memramcook sandstones and conglomerates, Albert mudstones are several hundred metres thick in the Maritime Oilfields Limited No. 2 well (borehole No. 26, Plates 92-34 to 92-36). The same mudstones, with minor interbeds of sandstone and conglomerate, are seen east of Maritime Oilfields No. 2 well in exposures along small brooks draining east into the Memramcook River (McLeod and Ruitenberg, 1978). The best subsurface reference section of interbedded grey and red mudstone is the interval between 758 m and 1 261 m in Irving/Chevron Little River No. 1 well (borehole No. 4, Plates 92-34 to 92-36).

Stratigraphically, the mudstone facies (Am) occurs only in the basal or medial parts of the Albert Formation between Elgin and Turtle Creek (Plate 92-36). However, east of Turtle Creek and north of the Boudreau Fault, the Albert Formation changes from dominantly coarse-grained in the west to mainly fine-grained in the east (see Plate 92-36 and compare the abbreviated lithologs for borehole Nos. 5 and 19, and 5 and 28). Consequently, east of Turtle Creek, the mudstone facies occurs not only at the base but also at the top of the formation. The upper mudstones form an elliptical-shaped geometry surrounding evaporite facies (Ae) in the area around Weldon (Plate 92-36).

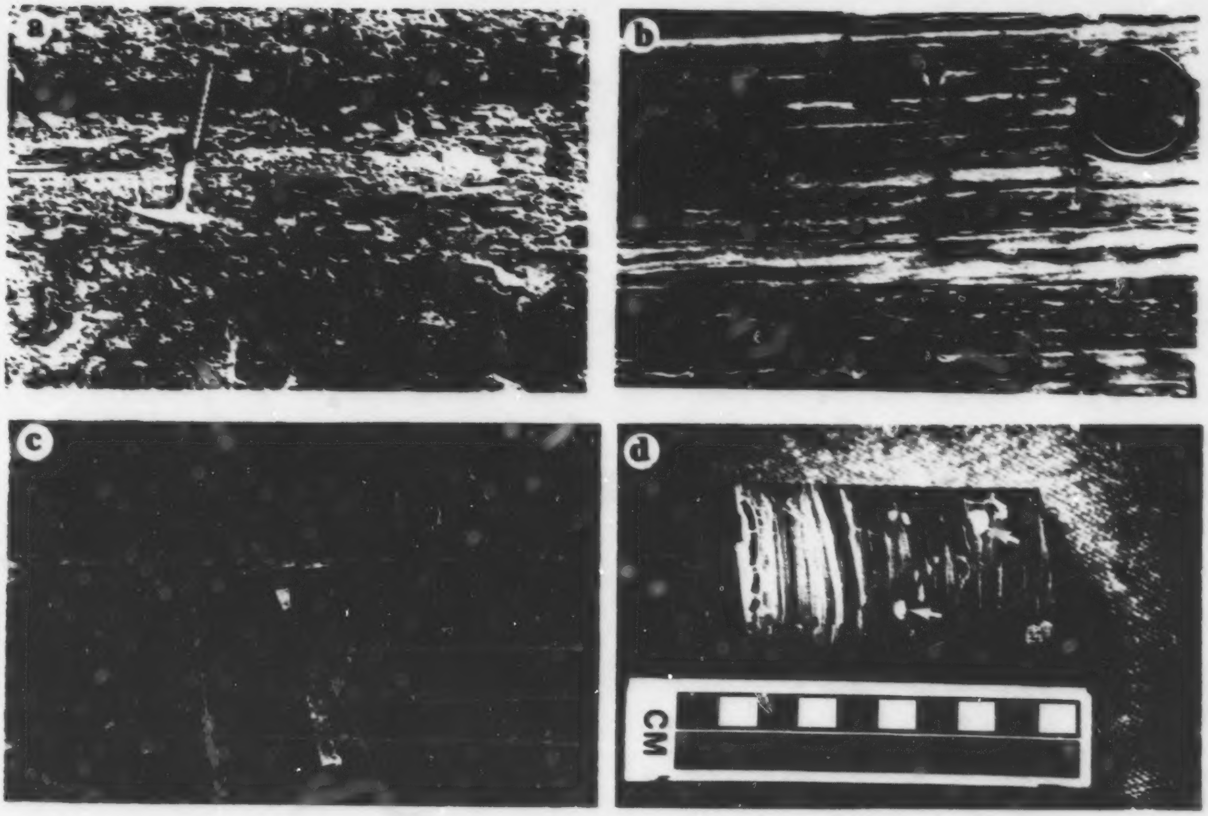

Figure 20: Albert Formation Mudstone Facies (Am). (a) Interbedded massive hackly fracturing mudstone (below hammer) and parallel-laminated mudstone (behind hammer handle) in mudstones at the Boudreau Village section along Petitcodiac River; (b) Parallel continuous to lenticular laminae of fine-grained sandstone (light grey) in dark grey mudstone at the Boudreau Village section. Coin is 19 mm in diameter; (c) Curled-up mudcracks in mudstones in the Boudreau Village section; (d) Dark grey mudstone with parallel laminae of light grey siltstone and fine-grained sandstone. Beds contain scattered diagenetic nodules of light grey limestone (arrows). Sample is from Province of New Brunswick Rosevale No. 3 corehole. See Brown and Whaley (1986) for details.

Lithology

Mudstone sections in the lower part of the Albert Formation are in many places red or interstratified red and greenish grey. In these sequences, joint surfaces or shears are commonly green, apparently as a result of reduction of iron-bearing minerals. Mudstone beds in the upper part of the formation are mainly grey.

The fracture habit of the mudstones varies from crumbly to hackly. Beds of shale range from platy to locally fissile.

The mudstone intervals range from beds 1 cm in thickness to sections several tens of metres thick. Some beds are massive, but most show some type of lamination (Figure 20a). The most common laminae are continuous to lenticular parallel layers of silt or fine-grained sandstone (Figures 20b and 20d). Current- or wave-rippled silt and sand laminations are locally observed. The more fissile beds show thin discontinuous laminae of brown or black kerogen.

The mudstones are in many places calcareous and/or dolomitic. This is particularly evident in the grey laminated mudstones that interfinger with and overlie evaporite facies (Ae) near Weldon. In this area it is quite common for the calcareous or dolomitic mudstones to grade into laminated muddy micrite or dolomicrite. On visual inspection the micrites and dolomicrites are indistinguishable from adjacent mudstones.

In the Weldon area, the mudstones that overlie evaporite facies (Ae) are salty, for example, in mudstones in Sifto No. W3 well (borehole No. 36, Plates 92-34 to 92-36) the degree of saltiness and therefore the content of soluble salts generally increase down section from the Weldon/Albert contact at 196.6 m to the Albert mudstone facies (Am)/evaporite facies (Ae) contact at 264.6 m (Figure 22, page 58). The soluble salts are too fine-grained to be seen with the unaided eye. But since halite and glauberite are the only significant soluble salts in the underlying evaporite facies (Ae) it is very likely that one or both of these minerals account for the salty taste in the mudstones. Nodules and thin laminae of fine-grained gypsum crystals are also present in the salty mudstones at Weldon.

Mudcracks are very common in the mud beds (Figure 20c); rain prints are less abundant. In addition to mudcracks, other evidence of aridity includes diagenetic pre-compaction light grey irregular aphanitic limestone nodules or caliche (Figure 20d). In rare cases, such nodules are densely packed and coalesce to form thin limestone beds. Mudstones that overlie the evaporite facies (Ae) at Weldon contain isolated and coalesced nodules of gypsum (Figure 21a). These beds also have gypsum-filled mudcracks (Figure 21b); some beds are cut by later gypsum veins (Figure 21c). Some grey mudstone and shale beds contain fish scales and fine detrital plant fragments.

Smith (1985) determined the inorganic composition of Albert mudstones by X-ray diffraction analyses. The minerals and their percentage means for 21 samples are: illite (26.2), chlorite (7.2), smectite (3.9), kaolinite (3.6), albite (16.4), potassium feldspar (3.1), quartz (7.9), analcime (9.6), dolomite (13.1), calcite (5.1), and pyrite (0.6). In hand specimen the abundance of illite is evident from a micromicaceous sheen on bedding planes. The presence of calcite is shown by a slight to moderate reaction to cold 10 per cent hydrochloric acid. Strata that are brown or brownish grey typically give a vigorous reaction to warm 10 per cent HCl revealing abundant dolomite. Pyrite is typically present as small nodules or disseminated grains in grey mud rocks. Quartz and feldspar minerals are mainly restricted to silt and sand laminations. Analcime occurs in grey mudstones with less than 7 per cent total organic carbon (Macauley and Ball, 1982; Smith, 1985). Mossman, *et al.* (1987) have reported an organic carbon content of 0.73 weight per cent from 22 samples of "organic matter-poor" mud rocks (Smith, *et al.*, 1991).

Sandstone is the most significant minor lithotype in the mudstone facies. It is typically grey. However, beds may be red-brown where interbedded with red mudstones. The sandstone occurs in beds 1 to 40 cm in thickness. The small size of most outcrops prohibits a clear statement of the three-dimensional shape of sandstone beds. Most of those observed have parallel lower and upper contacts; however, lenticular beds have been observed. The basal contact of most sandstone beds is sharp. Mudstone intraclasts in some beds indicate local erosional bases. Basal load casts are rare. The upper contact of sandstone layers are either sharp or gradational into overlying mudstone.

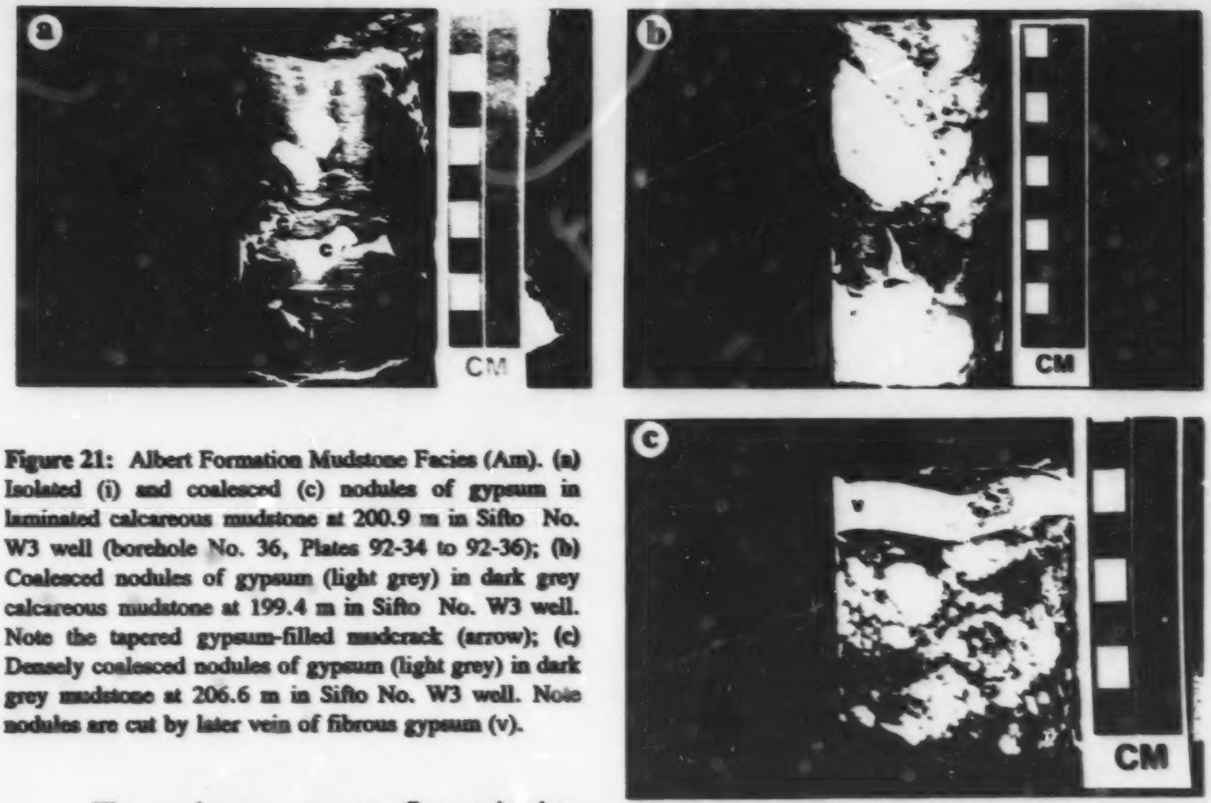

Figure 21: Albert Formation Mudstone Facies (Am). (a) Isolated (i) and coalesced (c) nodules of gypsum in laminated calcareous mudstone at 200.9 m in Sifto No. W3 well (borehole No. 36, Plates 92-34 to 92-36); (b) Coalesced nodules of gypsum (light grey) in dark grey calcareous mudstone at 199.4 m in Sifto No. W3 well. Note the tapered gypsum-filled mudcrack (arrow); (c) Densely coalesced nodules of gypsum (light grey) in dark grey mudstone at 206.6 m in Sifto No. W3 well. Note nodules are cut by later vein of fibrous gypsum (v).

The sandstones are very fine-grained to medium-grained. They are slightly to moderately calcareous and most show abundant detrital mica on bedding surfaces. Plant fragments are very abundant on some bedding planes. The sandstones usually contain abundant quartz, feldspar, and lithic clasts set in a matrix of carbonate, chlorite, and minor optically unresolvable clay minerals.

A few massive and/or normally graded sand beds have been seen. The great majority of beds are laminated. Typically, the base of the beds show parallel laminations and the upper part current- or wave-generated ripples. The current-generated structures are evident as cross laminae with a consistent unidirectional foreset sense or as asymmetrical ripples. Wave-generated structures are apparent from (1) cross laminations with opposing foreset directions within individual beds; (2) bundle-wise upbuilding of cross laminae into symmetrical ripples (de Raaf, *et al.*, 1977); and (3) interference ripple marks. In the northern part of the section on the east bank of the Petitcodiac River near Boudreau Village (Plates 92-34 and 92-36), beds of sandstone have parallel laminations in the lower part and wave-generated ripples in the upper part suggesting initial current-generated transport and subsequent wave reworking.

The mudstone facies locally contains beds of coarse-grained sandstone or pebble conglomerate. Strata of this type range from 2 to 100 cm in thickness. The base of such beds are typically sharp or erosional into underlying mudstone. The beds of coarse sandstone and conglomerate are similar to those within CONGLOMERATE

FACIES (Ac) (see pages 28-33).

Depositional Environment

The mudstone facies is interpreted to have been deposited mainly on mudflats near the margin of a lake. Some beds were undoubtedly deposited in "shallow" water within the lake. The word "shallow" is used only in a relative sense, i.e., above storm wave base.

A lake existed throughout most of Albert time (Greiner, 1962, 1974; Smith, 1985; Carter, 1985; Pickerill, *et al.*, 1985). During earliest and latest Albert time, the lake is believed to have been an ephemeral or playa lake (see below under EVAPORITE FACIES (Ae)).

The mudstones in the lowest part of the formation are red and grey, and contain abundant mudcracks and paleosol horizons. This, with the near absence of organic matter preservation (i.e., muds containing kerogen or algal laminae), suggests deposition on mudflats perhaps representing the most distal part of alluvial fans. The intertonguing of fine-grained mudflat and playa deposits with coarse-grained, braided stream and alluvial fan strata is often reported in arid intermontane basins (Bull, 1972; Link and Osborne, 1978; Miall, 1981). Reeves (1970) describes the origin, classification and geologic history of caliche in Texas and New Mexico.

The presence of algal bearing laminations and fish detritus in mudstones above the basal muds infers the establishment of a perennial body of water. Further evidence that the mudstone facies in part represents shallow lacustrine sedimentation is shown by wave-formed ripples at the top of many sand beds. The sands are believed to have been transported by distributary streams across upland alluvial fans and deposited as sheet wash deposits either on the mudflat or within the lake. Mudcracks in grey kerogen-bearing mudstones and shales suggest that the lake waters were shallow in this environmental setting and that the muds were intermittently exposed. The low total organic carbon content of the mudstones also suggests a shallow lacustrine setting. The deep lacustrine mudstones of lithofacies (Ak) contain much higher organic carbon (see below under KEROGENOUS MUDSTONE FACIES (Ak), pages 68-72).

Analcime is restricted to grey organic matter-poor mud rocks. A plot of X-ray diffraction mineral percentages of analcime versus albite for mudstones and organic matter-poor mudstones suggests the analcime may in part be a reaction product from feldspar (see Table 3 and Figure 27 below under KEROGENOUS MUDSTONE FACIES (Ak)). The presence of analcime has been used to infer a lacustrine origin for the Triassic Pope Agie Formation, Wyoming (Picard and High, 1972). A possible diagenetic origin during closed-basin cycles has been suggested for analcime in lacustrine mudstones of the Triassic Lockatong Formation, New Jersey (Van Houten, 1962, 1965).

The mudstone facies in the upper part of the Albert Formation near Petitcodiac River interdigitates with evaporite facies (Ae) (Plate 92-36). The latter contains beds of glauberite and thick sections of rock salt (Hamilton, 1961; Webb, 1977). Glauberite has been reported from saline mudflat sediments adjacent to a salt pan in the Saline Valley, California (Hardie, *et al.*, 1978). This further implies that the Albert mudstone facies was in large part deposited on marginal lacustrine mudflats.

EVAPORITE FACIES (Ae)

The evaporite lithofacies consists of mostly rock salt and rock salt/carbonate mudstone breccia. There are minor beds of carbonate mudstone containing crystals, nodules, irregular layers and veins of halite, anhydrite and glauberite. Significant glauberite beds occur in the upper and lower parts of the facies.

Distribution and Stratigraphy

There are no surface exposures of the evaporites in the Moncton Subbasin. However, the facies has been intersected in several boreholes on the east and west sides of the Petitcodiac River near Weldon (Plate 92-36). Evaporites have also been cut in a core hole near Cornhill in the northwestern part of the subbasin (Plate 92-33). The evaporites near Weldon were discovered in 1920 by D'Arcy Exploration Company during drilling of an oil and natural gas exploration hole on the east side of the Petitcodiac River (Hamilton, 1961). Six additional exploration oil and gas wells penetrated the evaporites between 1929 and 1949. In 1961 Sifto Salt (1960) Limited sank four core holes into the salts on the west side of the Petitcodiac River to assess the glauberite potential there. The core for the Sifto holes is housed with the New Brunswick Department of Natural Resources and Energy at their core storage facility in Fredericton.

None of the Sifto holes penetrated the entire evaporite interval. The most complete section, 129 m, is available from Sifto's Weldon No. W3 hole, and accordingly the core from this hole is taken as a reference section for the evaporite lithofacies. The location of this hole is shown as Sifto Salt Ltd. Weldon No. W3 well (borehole No. 36, Plates 92-34 to 92-36), and an abbreviated log of the evaporite facies in the well is shown on Figure 22.

Hamilton (1961) provides a log of core from New Brunswick Gas and Oilfields Ltd. (N.B.G.O.) No. 112 well (borehole No. 35, Plates 92-34 to 92-36). Unfortunately, the core for this hole is no longer available, but the log in Hamilton (1961) indicates the evaporite sequence in the central, and probably thickest part of the lithofacies, is about 475 m thick.

The upper contact of the evaporite lithofacies at Weldon is defined by the upper surface of the first significant glauberite bed (Figure 22). The evaporites are overlain, underlain (Hamilton,1961), and laterally transitional with fine-grained siliciclastics and carbonates of mudstone facies (Am) (Plate 92-36). The map shown on Plate 92-36 implies that the evaporite facies defines the top of the Albert Formation in the Weldon area. The map is presented in this way only to display in plan view the approximate distribution of the lithofacies and not to imply the evaporites define the uppermost lithofacies in the Weldon area. Numerous boreholes in the area indicate that 35 to 175 m of typical Albert mudstones and shales overlie the evaporite facies at Weldon (Hamilton, 1961; Webb, 1977). Mudstone exposures along Boyd Creek contain "salt hoppers" (Gussow, 1953; Hamilton, 1961; Greiner, 1962), and accordingly may be facies equivalents of the subsurface evaporites.

Norman (1932) first described the evaporites under the designation Gautreau Formation. He further determined the Gautreau to be conformable with the underlying Albert and overlying Weldon formations. Greiner (1962) recognized the limited geographic extent of Norman's Gautreau Formation and accordingly assigned the evaporites to the upper part of the Albert Formation. In keeping with Greiner's observation as a local unit, Carter and Pickerill (1985b) assigned the Gautreau evaporites member status within the Albert Formation. In their figure 5 they show the Gautreau Member as a geographically restricted unit interdigitating with the upper part of Greiner's (1962) Hiram Brook Member. The lateral relationship of the Gautreau evaporites with the upper Albert Formation clastic strata is clear evidence of their facies equivalency; therefore, in this report the Gautreau evaporites are called the Albert Formation evaporite facies (Ae).

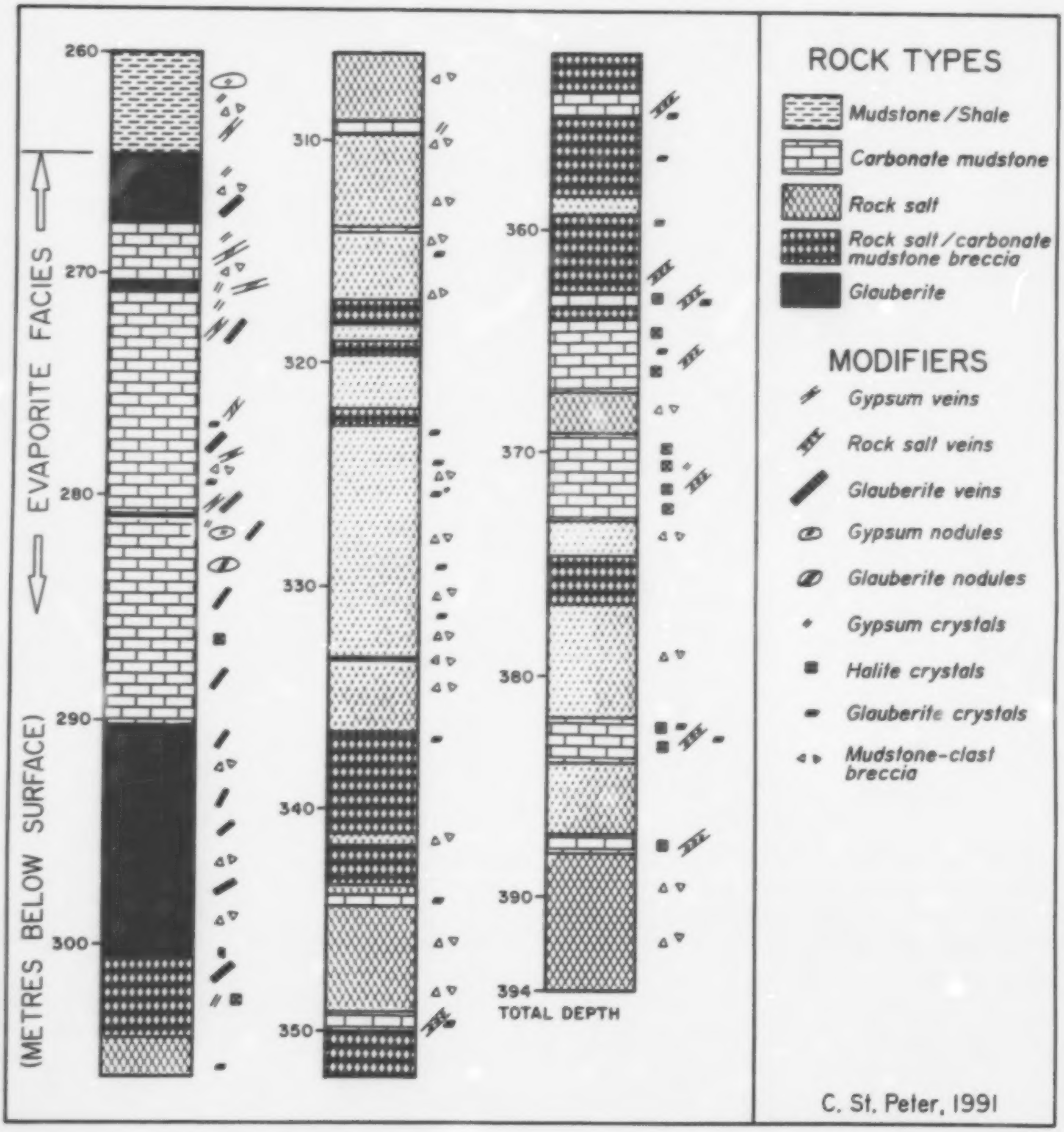
260
270
280
290
300
310
320
330
340
350
360
370
380
390
394
TOTAL DEPTH
EVAPORITE FACIES
(METRES BELOW SURFACE)
ROCK TYPES
Mudstone/Shale
Carbonate mudstone
Rock salt
Rock salt/carbonate mudstone breccia
Glauberite
MODIFIERS
Gypsum veins
Rock salt veins
Glauberite veins
Gypsum nodules
Glauberite nodules
Gypsum crystals
Halite crystals
Glauberite crystals
Mudstone-clast breccia
C. St. Peter, 1991

Figure 22: Lithologic log of Albert Formation evaporite facies (Ae) reference section at Sifto Salt (1960) Limited Well No. W3. See Plates 92-34 to 92-36 for location of well.

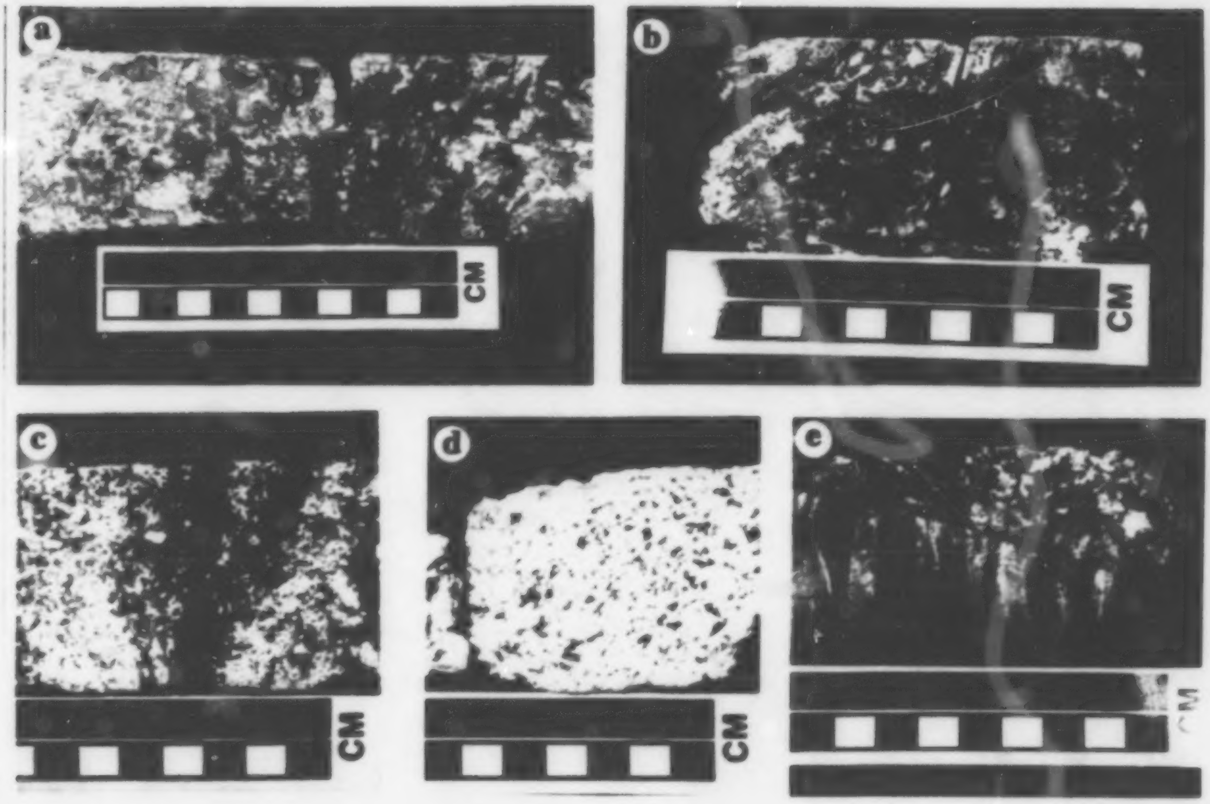

Figure 23: Albert Formation Evaporite Facies (Ae). (a) Smoky grey, coarse-grained rock salt from depth of 362 m below surface in Sifto Salt (1960) Ltd. No. W3 well. Note the angular inclusions of light grey carbonate mudstone (m); (b) Contact between rock salt (s) and carbonate mudstone (m) with a few crystals of chalky white glauberite (g) (or hydroglauberite) along contact, at depth of 314 m in Sifto No. W3 well; (c) Smoky grey rock salt with abundant intergrown chalky white glauberite at depth of 310 m in Sifto No. W3 well. Here, glauberite is coated with an efflorescent white crust of hydroglauberite or mirabilite; (d) Intergrown smoky grey rock salt and snow-white mirabilite or hydroglauberite, the latter apparently pseudomorphous after glauberite. Sample is from depth of 337 m below surface in Sifto No. W3 well; (e) Grey laminated carbonate mudstone cut by vein of coarse-grained rock salt (s) at depth of 331 m in Sifto No. W3 well.

Lithology

The core from Sifto No. W3 well (Figure 22) and also the log of N.B.G.O. No. 112 well (Hamilton, 1961) indicate that rock salt is the most abundant lithotype of the evaporite facies. The rock salt is typically coarse-grained and ranges in colour from pink to white to smoky grey (Figure 23a). The salt occurs in beds less than 1 m thick up to sections greater than 20 m in thickness (Hamilton, 1961). Beds of rock salt are rarely ever pure salt; angular clasts of light to dark grey carbonate mudstone and thin beds of carbonate mudstone are commonly present (Figures 23a and 23b). With an increase in the content of carbonate mudstone clasts, rock salt grades into mudstone breccia. This common lithotype is shown on Figure 22 as rock salt/carbonate mudstone breccia.

Clean rock salt and rock salt that forms

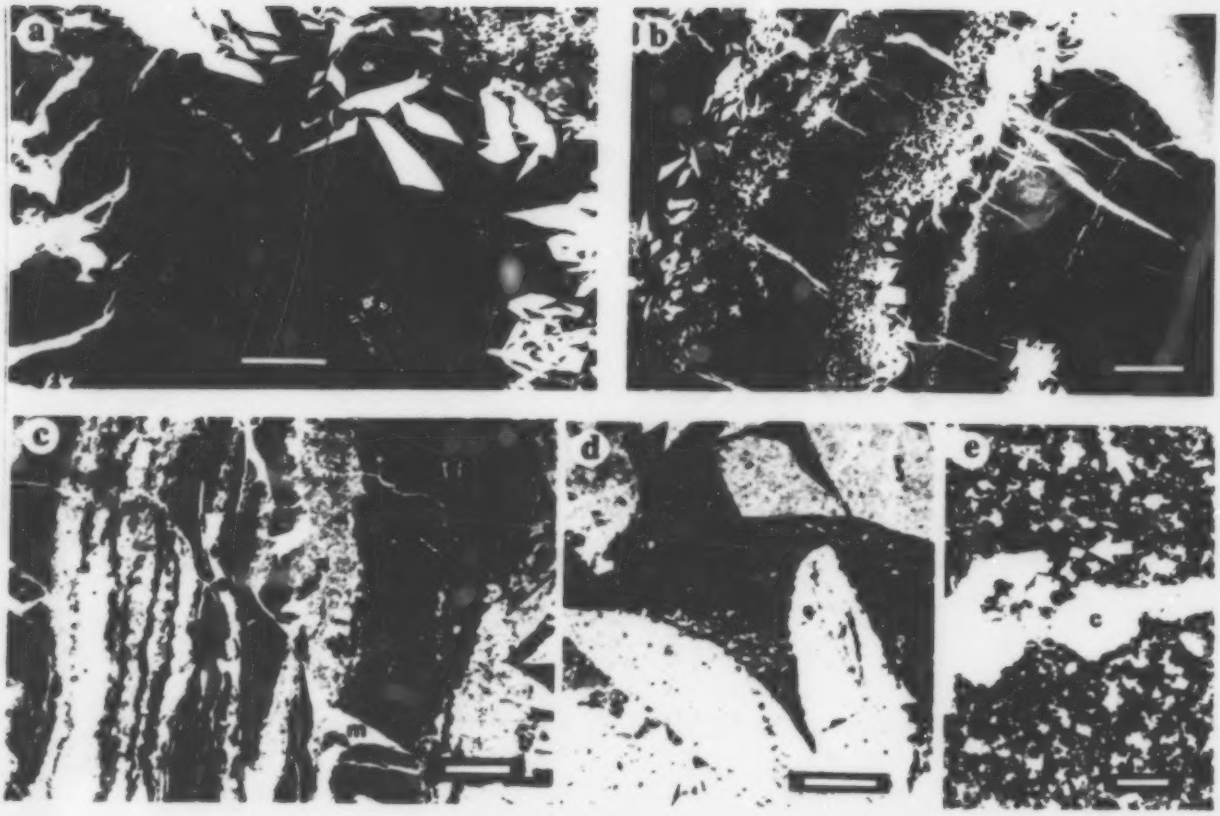

Figure 24: Albert Formation Evaporite Facies (Ae). (a) Photomicrograph of carbonate mudstone with parallel laminae of siliciclastic silt at depth of 286.3 m in Sifto No. W3 well. Sample shows slump fold, the nose of which is overgrown by porphyroblasts of unstrained gypsum. Unpolarized light. Scale bar is 2 mm; (b) Photomicrograph of carbonate mudstone with laminae selectively replaced by euhedral gypsum. Note gypsum-filled mudcracks that originate from gypsum-crowded laminae and propagate downwards to variable depths. Sample from depth of 286.3 m in Sifto No. W3 well. Unpolarized light. Scale bar is 4 mm; (c) Photomicrograph of carbonate mudstone with extensive replacement of laminae by small crystals and larger porphyroblasts of glauberite. Glauberite also occurs as nodules (n), sheet cracks (s) and downward-narrowing mudcracks (m). Sample is from 293.3 below surface in Sifto No. W3 well. Unpolarized light. Scale bar is 3 mm; (d) Photomicrograph of glauberite porphyroblasts showing compactional drape of micrite and siliciclastic laminae. Sample is from depth of 349.4 m in Sifto No. W3 well. Unpolarized light. Scale bar is 0.5 mm; (e) Photomicrograph of carbonate mudstone showing small, mainly square-shaped molds (arrows) and an irregular cavity (c) that are believed to have been filled with halite. Sample is from depth of 343.0 m in Sifto No. W3 well. Unpolarized light. Scale bar is 0.2 mm.

the matrix of breccias, in places contain minor amounts of dispersed glauberite crystals (Figure 23c). In rare cases coarse glauberite crystals can account for 50 per cent or more of thin rock salt layers (Figure 23d). Also, narrow veins of glauberite are locally observed cutting the salt.

Micritic carbonate mudstone is the most significant minor lithotype of the evaporite facies. It occurs in intervals ranging from a few centimetres to greater than 10 m in thickness (Figure 22). The thickest beds occur in the upper and lower parts of the facies. The mudstone is typically parallel-laminated with colour laminae alternating from light grey to medium grey to dark grey (Figure 23e). The overall hue of the rock is usually dark grey. The mudstone also contains some light grey parallel siliciclastic silt to fine-grained sand laminae that typically have a sharp basal contact and grade upward into silt-free carbonate mud (Figure 24a). Small-scale slump folds are locally seen in the laminated mudstones (Figure 24a). In thin section, mudstones are seen to contain abundant evidence of desiccation. Mudcracks and sheetcracks (Smoot, 1978) are very common; both are usually both filled with gypsum or glauberite (Figures 24b and 24c).

Mudstone beds and mudstone intraclasts within the evaporites contain post-depositional (diagenetic) minerals. In parts of the lithofacies where glauberite beds are common, associated carbonate mudstones contain glauberite and gypsum crystals. The crystals show preferential growth along laminae, but also display crystallization transverse to laminae attesting to their post-depositional origin (Figures 24a to 24d, 25a and 25b). Rosettes of gypsum and glauberite, and randomly oriented porphyroblasts of gypsum and glauberite up to 2 cm in length, are common (Figures 24a, 24d and 25b). Gypsum porphyroblasts have overgrown the nose of synsedimentary slump folds (Figure 24a). This, along with the presence of compactional drape of host rock laminae over gypsum and glauberite porphyroblasts (Figure 24d), attests to the diagenetic origin of these minerals. Mudstone beds also locally contain diagenetic nodules of fine-grained gypsum and glauberite. [It should be noted that glauberite in the Sifto core has been replaced or is coated with a white powdery efflorescent mineral or minerals (Figures 23b, 23c, 23d, 25c, 25d and 25e). Glauberite commonly turns into gypsum and mirabilite or hydroglauberite upon exposure to air and hydration (Sonnenfeld, 1984)].

Carbonate mudstone beds and mudstone clasts in rock salt dominated sections, contain abundant halite crystals. Unfortunately, during thin section preparation the halite could not be prevented from dissolving and consequently its former presence is only indicated by "square" molds and scalloped-walled cavities (Figure 24e). Nevertheless, the textural evidence strongly suggests a secondary (diagenetic?) origin for the halite where it occurs within mudstone beds.

Nearly all mudstone beds are pervasively cut by a network of veins. The veins include coarse-grained halite, gypsum, and glauberite (Figure 23e). The veins are clearly secondary and crosscut depositional and diagenetic textures. In places, where veins are abundant, mudstones are seen to grade into mudstone-clast breccias such as the halite-mudstone breccia described above.

Glauberite and glauberite-rich intervals up to 10 m in thickness occur in the upper and lower parts (Hamilton, 1961) of the evaporite facies (Figure 22). Like the associated rock salt, glauberite rarely occurs as pure monomineralic beds (Figure 25c). It typically contains minor to significant quantities (up to 50 per cent) of angular carbonate mudstone intraclasts (Figure 25d) and thin mudstone interbeds (Figures 25d and 25e). The presence of abundant glauberite crystals within mudstone beds and mudstone intraclasts clearly shows that the mineral formed within the host mud matrix and did not precipitate for example from a standing body of water. Replacement was locally so complete that virtually pure glauberite layers resulted (Figure 25c).

Depositional Environment/Paragenesis

The non-siliciclastic minerals comprising evaporite facies (Ae) are micritic calcite, gypsum, glauberite, and halite. It is apparent from core in the Sifto No. W3 well that the first

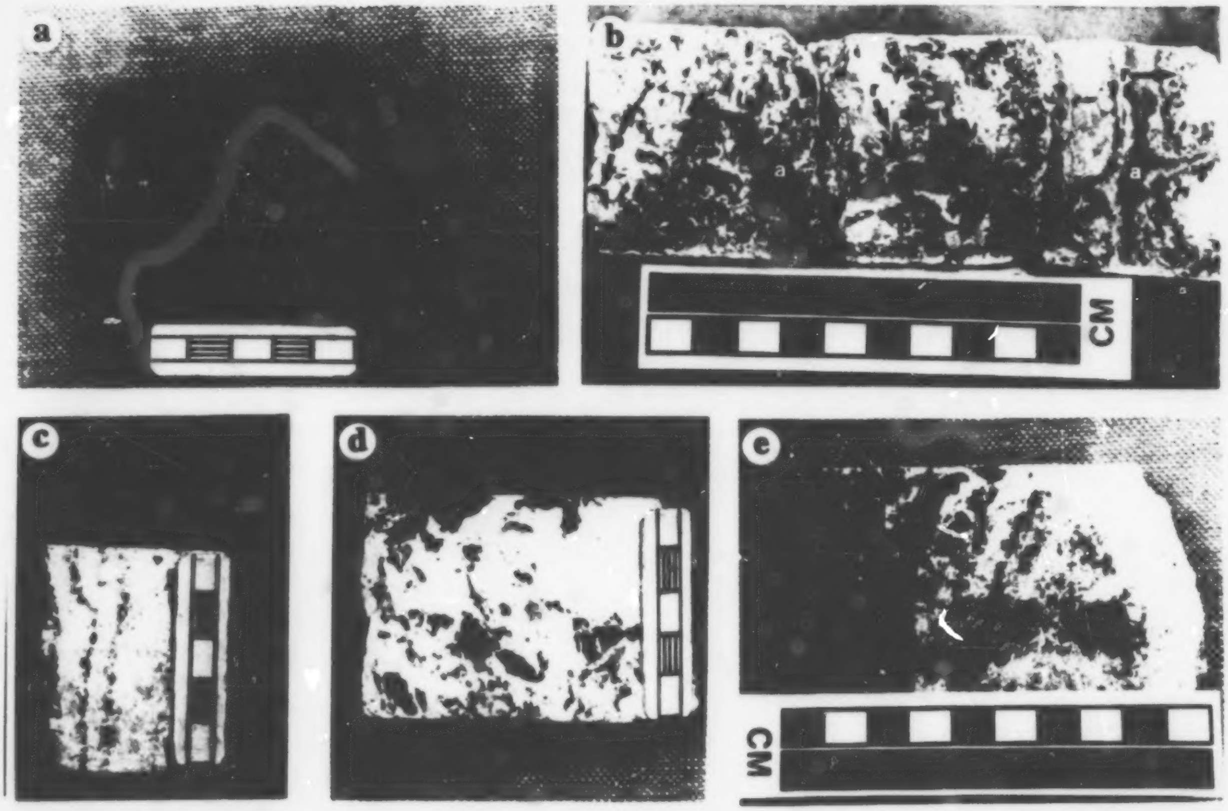

Figure 25: Albert Formation Evaporite Facies (Ae). (a) Dark grey carbonate mudstone with diagenetic(?) laminae of light grey, fine-grained gypsum at depth of 265 m in Sifto Salt (1960) Ltd. No. W3 well. Scale in centimetres; (b) Aphanitic (a), coarse swallow-tail rosettes (r), and isolated porphyroblasts (p) of glauberite replacing light grey mudstone at depth of 350 m in Sifto No. W3 well; (c) Glauberite altered to snow-white mirabilite or hydroglauberite. Evidence of glauberite replacement of mudstone is shown by the disaggregated laminae of dark grey mudstone. Sample from depth of 293 m below surface in Sifto No. W3 well. Scale in centimetres; (d) Glauberite (now mirabilite or hydroglauberite) containing angular intraclasts of dark grey host carbonate mudstone. Sample from 267 m below surface in Sifto No. W3 well. Scale in centimetres; (e) Contact between dark grey carbonate mudstone bed on left and snow-white mirabilite or hydroglauberite on right showing characteristic replacement of mudstone by the sulphate. Sample from depth of 298 m in Sifto No. W3 well.

evaporite mineral to crystallize was micritic calcite. It is essentially the host rock in which the other minerals subsequently grew. The micrite forms carbonate mudstone beds containing thin parallel laminae of siliciclastic silt and fine-grained sand. The uniformity of the micrite and the fact that it pre-dates synsedimentary folds clearly indicates an early (primary?) origin. It is not clear if the micrite precipitated chemically or biochemically from the lake waters. However, the absence of algal laminae, algal remains, fauna, or bioturbation, and the generally arid and saline conditions inferred from desiccation features and associated salts, nearly preclude a biogenic origin for the micrite.

The gypsum and glauberite have a diagenetic and epigenetic origin. There is no well preserved depositional evidence in Sifto No. W3 core that either of these minerals precipitated directly from a standing body of water. For example, there are no colour bands or delicate parallel chemical laminae (varves) that would be expected if the minerals were precipitated from a perennial saline lake (Hardie, *et al.*, 1978). Also, the log of the complete evaporite lithofacies at N.B.G.O. No. 112 well (Hamilton, 1961) shows the evaporite sequence is heralded by halite and not sulphate; the latter would normally precipitate first from saturation of a standing saline lake (Hardie, *et al.*, 1978; Picard and High, 1972). Textural evidence supporting a diagenetic origin for the gypsum and glauberite includes the growth of porphyroblasts, nodules and bedding-discordant layers replacing the host carbonate mudstones. Further evidence of early growth is shown by compactional drape of micrite and siliciclastic laminae around sulphate porphyroblasts. The textural relationships suggest that the diagenetic gypsum and glauberite formed from saturated brines within the carbonate muds below the sediment/lacustrine water interface or perhaps on a playa mudflat — saline mudflat of Hardie, *et al.* (1978) — under arid conditions. In this environment the Na-rich and Ca-rich brines giving rise to the sulphates resulted from: (1) saturation of the muds by groundwaters of the adjacent or superjacent playa lake; or (2) saturation in the vadose zone by capillary groundwater draw, that is evaporative pumping (Hsü and Siegenthaler, 1969). The presence of desiccation features in the carbonate mudstones implies the second process is undoubtedly involved in sulphate production.

An epigenetic origin is indicated for the gypsum and glauberite in places where the minerals occur as veins cutting earlier diagenetic minerals and/or the host carbonate mudstone.

Halite may in part be primary in origin. Hamilton (1961) for example reported the presence of very uniform horizontally bedded halite in the interval from 707 to 731 m in N.B.G.O. No. 112 well. However, no such stratified halite is seen in the Sifto No. W3 well.

Halite, like the gypsum and glauberite reported above, is largely of diagenetic origin. The halite is intergrown with gypsum and glauberite and also occurs as disseminated grains in the host mudstone. However, the greater part of the halite occurs as thick monomineralic intervals with widely distributed carbonate mudstone clasts. In all cases it is clear that the halite postdates the host mudstone and is accordingly interpreted to be diagenetic.

Halite, like the gypsum and glauberite, has in part undergone a late process of dissolution and reprecipitation to form monomineralic coarse-grained veins. Together, the obviously widespread diagenetic and epigenetic formation of halite preclude an assessment of possible primary chemical precipitation for the halite seen in the Sifto No. W3 core.

To conclude, calcite micrite and perhaps some halite of the Albert evaporites at Weldon are interpreted as primary saline lake deposits. The gypsum, glauberite, and most of the halite (as now seen) are either of diagenetic or epigenetic origin. The diagenetic phases are interpreted to have most likely formed by evaporative pumping of groundwater and concomitant crystal growth within carbonate muds on desiccated mudflats bordering an ephemeral or perennial saline lake. Carter and Pickerill (1985a, p. 81) interpreted the "evaporite suite as having formed in a shallow evaporitic lacustrine environment".

KEROGENOUS MUDSTONE FACIES (Ak)

This facies consists of kerogenous shale (oil shale), kerogenous mudstone, shale, mudstone, and minor sandstone, conglomerate, limestone, and dolostone.

Distribution and Stratigraphy

Kerogenous mudstone facies strata are exposed along several streams in the southeastern Moncton Subbasin. The most continuous exposures are at Frederick Brook about 2.5 km northwest of the community of Albert Mines (Plates 92-34 to 92-36). The community of Albert Mines derives its name from a nineteenth century mine in which albertite, a black vitreous solid bitumen, was removed from a vein that followed the course of the Edgetts Landing Fault (Figure 35d, page 101). Actually, the site of the abandoned albertite mine at Frederick Brook (see Plate 92-34 for location) is also known informally as Albert Mines. The kerogenous shales and mudstones along Frederick Brook were chosen by Greiner (1962) as the type section for his medial Frederick Brook Member of the Albert Formation (see above under Albert Formation, page 15). The oil shales at Frederick Brook are presently under lease to Canadian Occidental Petroleum Ltd.

Other good reference sections of kerogenous mudstone facies (Ak) are seen along: (1) an unnamed brook 1 km southeast of Boudreau Village; (2) the west bank of the Memramcook River just east of Taylor Village; (3) LeBlanc Creek immediately west of Saint-Joseph; (4) Downing Creek; (5) tributaries of Turtle Creek that lie east and west of Rosevale; and (6) Webster Brook, 2 to 3 km southwest of Elgin (Plate 92-36).

The thickness of the kerogenous mudstones at Frederick Brook along the hinge of the south-plunging anticline (Plate 92-35) is estimated from bedding attitudes and graphic construction to be about 550 m. Because the section is known to be cut by many minor(?) faults (Wright, 1922) and deformed by mesoscopic folds (St. Peter, 1988), the thickness estimate is tenuous. The section southeast of Boudreau Village is greater than 300 m thick; the basal part of the facies in this area is unconformably overlain by the Enragé Formation (Plate 92-34). The sections near Taylor Village and along LeBlanc Creek are too deformed (faulted or folded) to allow reliable thickness estimates.

The section on the lower part of Downing Creek has been intersected in N.B.G.O. No. 57 and Petro-Canada Dover No. 2 wells (borehole Nos. 24 and 25, Plate 92-36). The drill intersections combined with surface bedding attitudes indicate a kerogenous mudstone interval about 150 m in thickness in this area. At Rosevale the kerogenous facies has a true thickness of about 200 m in N.B.G.O. No. 59 well (borehole No. 33, Plate 92-36).

The section along Webster Brook southwest of Elgin is incomplete; it is cut off to the west by the Elgin Fault. North of Webster Brook, at Irving/Chevron Lee Brook No. 1 well, the kerogenous mudstone facies has an apparent and maximum thickness of 250 m (see abbreviated log of borehole No. 1, Plate 92-36). In summary, the thickness of kerogenous mudstone facies (Ak) in the southeastern Moncton Subbasin ranges from 150 m to a maximum of perhaps 550 m.

Stratigraphically the kerogenous mudstone facies in the southeastern Moncton Subbasin lies in the central part of the Albert Formation, an observation first made by Wright (1922). Greiner (1962) formally designated these beds as the Frederick Brook Member of the Albert Formation. However, the kerogenous strata are not continuous throughout the Moncton Subbasin (cf., Greiner, 1962) and accordingly Greiner's three-member subdivision of the Albert is dropped here. As noted above under SANDSTONE FACIES (As), page 40, the kerogenous mudstones in most places in the southeastern Moncton Subbasin are overlain by thick sandstone of sandstone facies (As). This is apparent from surface sections and many of the abbreviated logs shown on Plate 92-36.

The presence of abundant thick oil shale beds in the Albert Formation has been known for nearly 150 years. The beds along Frederick Brook were known to early geologists prior to the discovery of the famous albertite vein there by John Duffy in 1849 (Dawson, 1853, 1868; Pickerill, *et al.*, 1985; St. Peter, 1987b, 1988). The oil shales achieved widespread attention by paleontologists in the early part of the twentieth century following the discovery and description of whole palaeoniscid fish skeletons at Frederick Brook (Figure 28c, page 71) (Lambe, 1909, 1910). Several drilling programs and organic geochemical assay tests have been undertaken in the past 50 years to determine the commercial potential of the oil shales (Alcock, 1948; Timm, 1948; Worth, 1975; Macauley and Ball, 1982, 1987; Wright, 1982; Brown and Whaley, 1986; St. Peter, 1988). The Albert oil shales are widely believed to hold the highest potential for commercial development of all the oil shales in Canada (Figure 35c, page 101) (Macauley, 1981; Macauley and Ball, 1982; Macauley, *et al.*, 1984). Correlative oil shales in the Horton Group in Nova Scotia have been recently thoroughly described by Smith and Naylor (1990).

Lithology

The organic matter-rich and organic matter-poor lithotypes comprising kerogenous mudstone facies (Ak) have been described in great detail by Smith (1985), and by Smith and Gibling (1987). Smith (1985) logged three core holes, two of which cut the beds at Downing Creek, and the third which cuts strata at Frederick Brook. He has shown that there is a complete spectrum of lithotypes from very organic matter-rich fissile microlaminated oil shales through to organic matter-poor massive unlaminated mudstones. For the purpose of this report the organic matter-rich lithotypes are designated: laminated kerogenous mudstone, laminated kerogenous shale (oil shale), and massive kerogenous mudstone.

Laminated kerogenous mudstone is the most abundant lithotype in the kerogenous mudstone facies (Ak), designated as "oil shale C" by Smith (1985) and Smith and Gibling (1987), and called "massive dolomitic marlstone" by King (1963). Excellent exposures of this lithotype are seen in the Taylor Village section (Figure 26a). Good exposures also occur along Frederick Brook from the reverse fault that bounds the Albert Formation on the northeast to a point about 500 m up stream from that fault (Plates 92-34 and 92-36). See the locations of beds 2, 3, 4, and 5 in King (1963, fig.2).

The kerogenous mudstone is brown and weathers light grey or brown. It is typically parallel-laminated with laminae ranging in thickness from 0.6 mm to 10 mm. The rock commonly breaks with a subfissile or platy fracture (Figure 26a). Freshly ripped beds of this type break into large slabs a metre or more in width. The laminae comprise light-coloured silicate and carbonate-rich layers alternating with dark brown thinner organic matter-rich (kerogen) layers (Figure 26b). The kerogen laminae are typically discontinuous and when split parallel to bedding are seen to exist as isolated patches of organic matter (Figure 26c).

The kerogenous mudstone beds commonly contain disseminated pyrite grains, pyrite framboids (Smith, 1985), siderite nodules, and fish fragments. Ostracods are present in a bed at Downing Creek (Figure 26d).

X-ray diffraction (XRD) results given by Smith, *et al.* (1991) on ten samples of kerogenous mudstones from core samples at Downing Creek and Frederick Brook are shown in Table 2. Scanning electron microscopy observations indicate that albite in Albert sandstones results from diagenetic alteration of detrital plagioclase

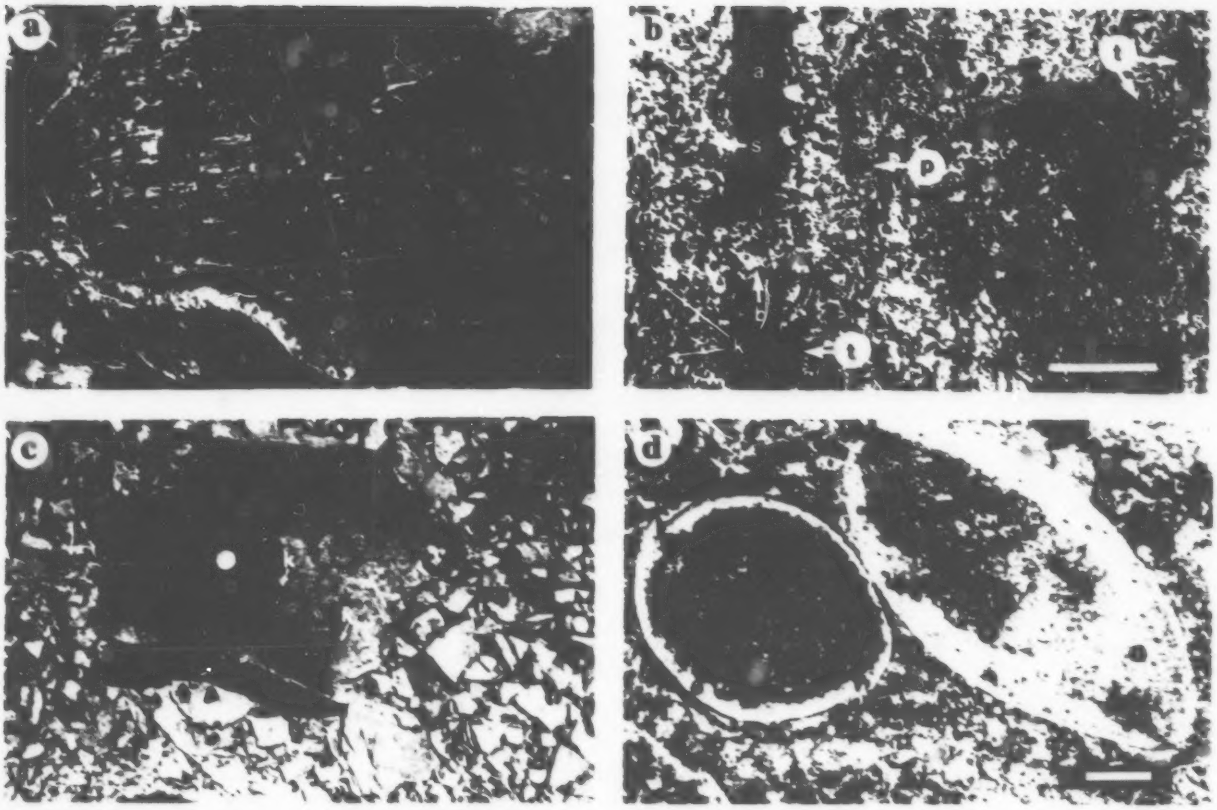

Figure 26: Albert Formation Kerogenous Mudstone Facies (Ak). (a) Laminated kerogenous mudstone in the section on the west bank of the Memramcook River near Taylor Village. Note subfissile or platy fracture; (b) Photomicrograph of laminated kerogenous mudstone showing fine-grained peloidal algal carbonate lamina (a), siliciclastic-rich lamina (s), and subtle kerogen-rich lamina (k). The algal lamina is burrowed (b); the siliciclastic-rich lamina contains irregular patches of dolomicrite (dark grey), algal peloids (p), and indeterminate algal bodies (telalginite) (t). Sample is from Frederick Brook. Plane-polarized light. Scale bar is 4 mm; (c) Laminated kerogenous mudstone shows characteristic isolated patches of dark grey kerogen (k) on bedding surfaces. Sample is from the Canadian Occidental Petroleum Ltd. test pit at Frederick Brook. Coin is 21 mm in diameter; (d) Photomicrograph of ostracods in dolomitic kerogenous mudstone at Downing Creek. Plane-polarized light. Scale bar is 100 μm.

and potassium feldspar (Chowdhury and Noble, in press). It seems reasonable to interpret a similar paragenesis for the albite in kerogenous mudstones and also in the other organic matter-rich Albert mud rocks.

Analcime occurs in laminated kerogenous mudstone, yet it has not been detected in organic matter-rich kerogenous shale (see below, page 72). It occurs in beds with less than about 7 per cent total organic carbon (TOC) (Macauley and Ball, 1982; Smith, 1985; Smith, *et al.*, 1991). Macauley and Ball (1982), Macauley, *et al.* (1985) and Mossman, *et al.* (1987) have concluded that analcime occurs in Albert mud rocks with low total clay content. XRD data in Macauley and Ball (1982) and Smith (1985) do not support this conclusion. For example, the tabular data in Macauley and Ball (1982) show a mean clay content of 10.8 per cent for 121 samples

Table 2: X-ray diffraction average mineral weight percentages, fluorescence microscopic maceral percentages, and total organic carbon (TOC) of organic matter-rich lithotypes of Albert Formation from core samples near Downing Creek and Frederick Brook (modified after Smith, *et al.* , 1991).

LITHOTYPE	OIL SHALE	LAM.KER.MDST	MASS.KER.MDST.
No. of Samples	16	10	2
Quartz	11.5	9.6	8.4
Albite	15.3	12.4	8.8
Kspar	2.2	5.0	9.5
Illite	40.6	28.7	38.3
Smectite	0.9	2.1	0.7
Kaolinite	0.6	1.6	0.7
Chlorite	0.9	3.4	1.0
Calcite	14.2	8.5	24.5
Dolomite	11.1	15.7	6.3
Siderite	1.0	0.6	1.4
Analcime	-	11.1	-
Pyrite	1.0	4.1	1.2
MACERALS			
No. of Samples	16	3	1
Lamalginite	79.6	51.4	2.0
Telalginite	0.9	0.4	5.6
Liptodetrinite	14.4	42.9	82.0
Sporinite	2.3	3.5	6.3
Fusinite	2.3	1.0	3.3
Vitrinite	0.5	0.8	0.6
TOC	10.85	2.92	7.26

that contain no analcime, but a mean clay content of 13.2 per cent for 10 samples with analcime. Also, the XRD mineral percentages for 58 samples given in Smith (1985, p. 66) show that both analcime-bearing and analcime-free mud rocks contain virtually identical mean total clay contents of 40 per cent.

The content of analcime in organic matter-poor Albert mud rocks does, however, show some correlation with albite content. For example, a linear regression analysis of analcime on albite — for method see Krumbein and Greybill (1965) — for 25 samples of mudstone and laminated kerogenous mudstone from Downing Creek gives a weak negative correlation coefficient (r) of -0.227 (Table 3). Although the data indicate a fairly wide degree of scatter (Figure 27), there is a discernible inverse relationship between albite and analcime. It is implied from this that the analcime may at least in part originate from feldspar. Other variables such as the composition of pore fluids have undoubtedly influenced the formation and quantity of analcime generated.

Macauley and Ball (1982) have also noted that analcime is generally associated with Albert mud rocks with low feldspar content. In 96 samples that they analyzed from Frederick Brook only one organic matter-poor mud rock recorded any analcime. It contained 32 per cent analcime and 6 per cent feldspar. In contrast, 7 analcime-free core samples from the same hole (Canadian Occidental Petroleum, Albert Mines No. 7) contained an average of 23 per cent feldspar.

Analcime is believed to have originated from clays or zeolite precursors in moderately alkaline lake waters in the Parachute Creek Member of the Green River Formation, Colorado (Brobst and Tucker, 1973). In the Carboniferous Rocky Brook Formation of western Newfoundland analcime in fine-grained lacustrine clastics and carbonates has been attributed to: (1), direct precipitation from lakewater or porewater, or (2), reaction of those waters with a clay mineral or plagioclase precursor (Gall and Hyde, 1989).

Calcite and dolomite are the only significant carbonates in the kerogenous mudstones. It is very likely that the dolomite is mainly ankeritic. Chowdhury and Noble (1989) determined from SEM on 12 shale samples an average ankerite content of 18.3 per cent. Similarly, White, *et al.* (1988) found ankerite to be more abundant than dolomite in oil shales at Frederick Brook. Link and Osborne (1978) report that ferroan dolomite is common in lacustrine mud rocks of the Ridge Basin, California. Dolomite (ankerite) in the kerogenous mudstones of the Albert Formation is very fine-grained, indicating that it probably did not arise from recrystallization of a pre-existing calcium carbonate. Brobst and Tucker (1973) used this evidence to argue an origin by primary chemical precipitation for dolomite in Green River Formation carbonate rocks. True primary dolomite is precipitating in the modern Coorong Lakes, South Australia (Warren, 1990).

Total organic carbon (TOC) content of three samples of kerogenous mudstone from core samples at Dover and Albert Mines averaged 2.9 per cent (Smith, *et al.*, 1991). Organic petrography on the same samples indicated the kerogen laminae are discontinuous and comprise subequal quantities of lamalginite and liptodetrinite (Table 2).

Kerogenous shale (oil shale) is the second most abundant lithotype in the kerogenous mudstone facies (Ak). Beds of oil shale are exposed at Frederick Brook about 100 m north of the confluence of the two tributaries shown on Plates 92-34 to 92-36. Canadian Occidental Petroleum Ltd. has a test pit in this oil shale bed in the field on the east side of Frederick Brook (St. Peter, 1988). Organic matter-rich oil shale

Table 3: Correlation and calculation of least squares linear regression line of albite (Al) versus analcime (An) for Albert Formation mudstones and laminated kerogenous mudstones from cores at Downing Creek. XRD mineral percentages are from Smith (1985, p.66).

Al=x	An=y	xy	x^2	y^2
21.3	1.5	32.0	453.7	2.3
6.1	10.1	61.6	37.2	102.0
5.3	5.6	29.7	28.1	31.4
12.1	8.1	98.0	146.4	65.6
3.7	8.7	32.2	13.7	75.7
6.6	15.4	101.6	43.6	237.2
16.0	13.5	216.0	256.0	182.3
4.9	17.6	86.2	24.0	309.8
4.1	15.7	64.4	16.8	246.5
10.2	4.9	50.0	104.0	24.0
5.2	12.4	64.5	27.0	153.8
7.6	19.5	148.2	57.8	380.3
16.5	13.7	226.1	272.3	187.7
6.2	16.9	104.8	38.4	285.6
16.1	5.1	82.1	259.2	26.0
7.1	27.4	194.5	50.4	750.8
19.6	8.5	166.6	384.2	72.3
21.3	2.7	57.5	453.7	7.3
25.6	16.5	422.4	655.4	272.3
28.3	8.0	226.4	800.9	64.0
2.7	13.5	36.5	7.3	182.3
17.2	19.4	333.7	295.8	376.4
11.3	12.3	139.0	127.7	151.3
6.1	5.1	31.1	37.2	26.0
10.1	4.0	40.4	102.0	16.0
ΣX	ΣY	Σxy	Σx^2	Σy^2
291.2	286.1	3045.4	4692.8	4228.4

N=25

$X=291.2/25=11.6$

$Y=286.1/25=11.4$

$\sigma_x^2=1/N\Sigma x^2-(x)^2 = 53.2$

$\sigma_x=\sqrt{\sigma_x^2}=7.3$

$\sigma_y^2=1/N\Sigma Y^2-(Y)^2 = 39.2$

$\sigma_y=\sqrt{\sigma_y^2} = 6.3$

$$r=\frac{\underline{1/N\ \Sigma xy-xy}}{\sigma_x\sigma_y}$$

$$=\frac{\frac{3045.4}{25}-(11.6)(11.4)}{(7.3)(6.3)}$$

$$\approx -0.227$$

$$Y-Y=r\left(\frac{\sigma_y}{\sigma_x}\right)(X-X)$$

$$Y-11.4=-.227\left(\frac{6.3}{7.3}\right)(X-11.6)$$

$$Y= -.196X+13.7$$

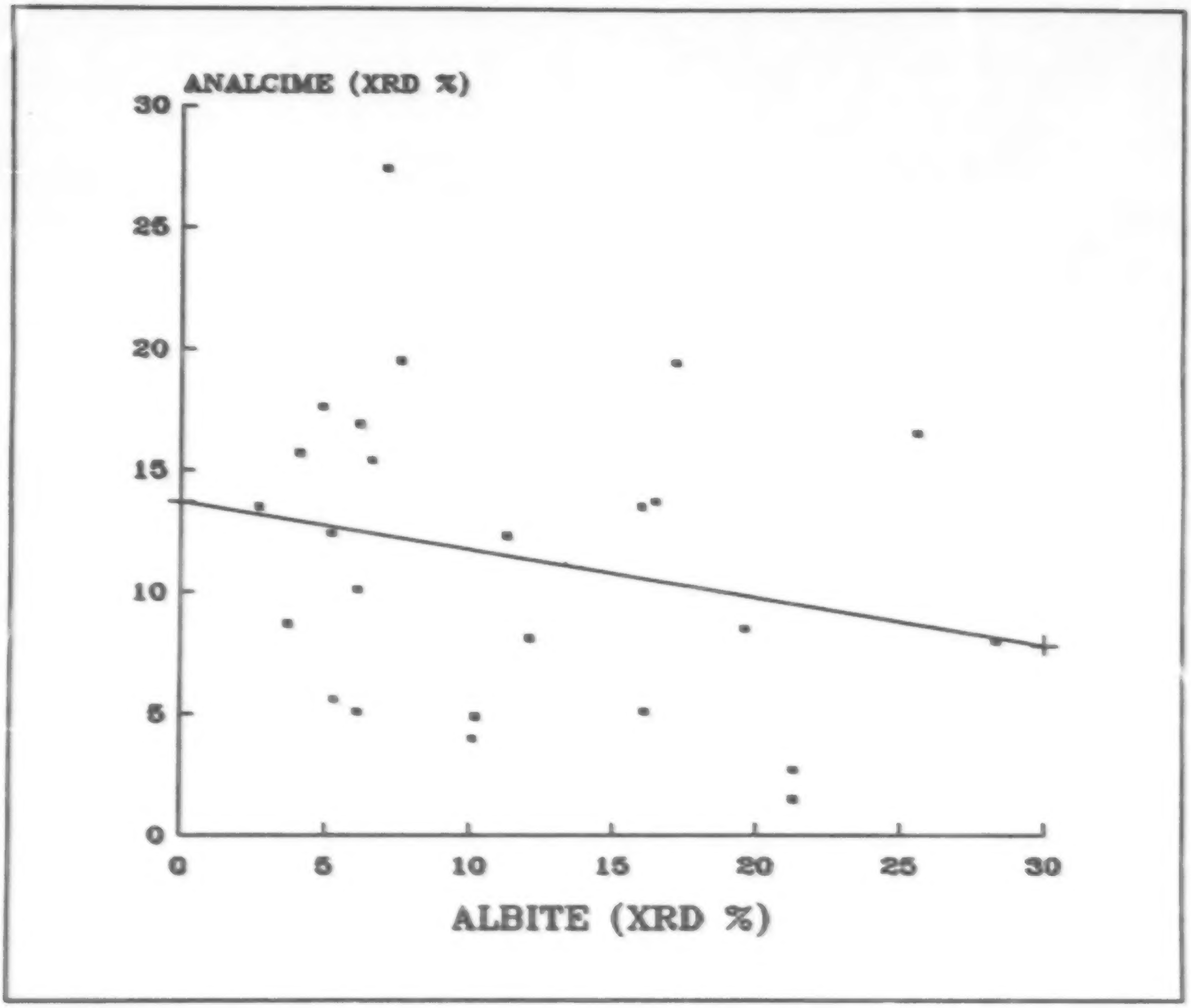

Figure 27: Least squares linear regression line of analcime on albite for 25 samples of Albert Formation mudstones and laminated kerogenous mudstones from cores at Downing Creek. See Table 3 for details.

beds are also seen in several exposures on the west tributary of Frederick Brook. Oil shale beds crop out on the north side of the reservoir along LeBlanc Creek about 700 m west of Saint-Joseph. The same beds are seen on the north side of Boyd Creek where they were intersected in Petro-Canada Dover No. 2 well (see abbreviated log of borehole No. 25, Plate 92-36). Oil shale beds in the Rosevale area have been delineated from surface exposures and drill core (Brown and Whaley, 1986; St. Peter, 1988, 1989, map plate 89-104C). Oil shale beds also occur in the section at Webster Brook.

The oil shale beds in the Albert Formation range in thickness from a few centimetres up to 45 m. The most organic matter-rich bed at Frederick Brook has an average thickness of 19.8 m with an oil yield of 94.7 L/t (St. Peter, 1988). Beds of comparable thickness and yield

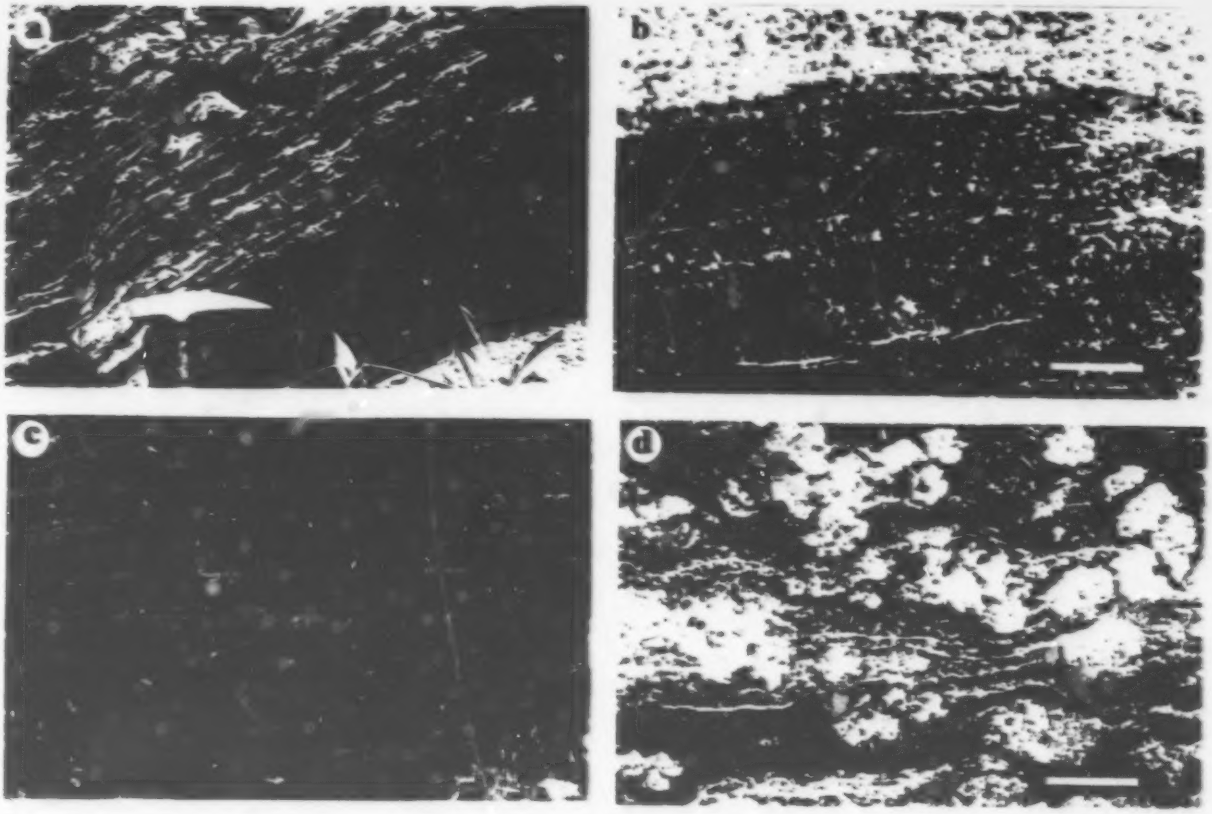

Figure 28: Albert Formation Kerogenous Mudstone Facies (Ak). (a) Fissile, microlaminated, kerogen-rich oil shale beds at Frederick Brook; (b) Photomicrograph of microlaminated oil shale at Taylor Village. Dark grey kerogen-rich lamina at bottom contains minor carbonate and siliciclastic silt. Light-coloured laminae at top is mainly silt-size dolomite. Plane-polarized light. Scale bar is 1 mm; (c) Palaeoniscid fish in oil shales at Frederick Brook. Coin is 19 mm in diameter; (d) Photomicrograph of pseudomorphous calcite after euhedral cubic mineral (halite?). Cross-polarized light. Scale bar is 2 mm.

have been drilled at Rosevale and Boyd Creek.

A prominent property of the oil shale beds is their fissility and varve-like or parallel microlaminated character (Figure 28a). The laminae range in thickness from 0.01 mm to 0.7 mm and comprise alternating tan-coloured clay and aphanitic carbonate-rich layers and dark brown kerogen-rich layers (Figure 28b). On weathered surfaces the shale quickly changes to a light or medium grey and the rock splits into fissile sheets often not much thicker than paper. King (1963) called these rocks "paper" shales. Beds of this type at Frederick Brook yield whole palaeoniscid fish skeletons (Figure 28c). Details of the various fish species are given in Lambe (1909, 1910). Locations of the fish-bearing beds are given in St. Peter (1987b).

The inorganic mineralogy of 16 samples of oil shale beds from Downing Creek and Frederick Brook cores has been given by Smith, *et al.* (1991). The average mineral percentages for their oil shale types "A" and "B" are shown here in Table 2, page 67. By comparing the averages for oil shale and those for laminated kerogenous mudstone, it is seen that fissile laminated oil shales contain more calcite and illite but less dolomite than associated laminated kerogenous mudstone. Also, the oil shale beds contain no analcime; this contrasts with laminated kerogenous mudstones, which contain about 11 per cent analcime. A thin section cut from an oil shale bed at Frederick Brook reveals pseudomorphous calcite after an euhedral cubic mineral (Figure 28d). The replaced diagenetic mineral may have been halite. Environmental implications of these results are discussed below on pages 77-78.

The average TOC content of the 16 oil shale samples described by Smith, *et al.* (1991) is 10.85 per cent which is almost four times that of the laminated kerogenous mudstone beds. Fluorescence microscopy on the samples shows that the organic matter-rich laminae comprise mainly lamalginite (79.6 per cent) and subordinate liptodetrinite (14.4 per cent) (Table 2). Additional data on organic petrography are given in Kalkreuth and Macauley (1984) and Smith, *et al.* (1991). The fluorescence data show that the kerogen is mainly derived from alginitic precursors. A fairly extensive organic geochemical database on the oil shales corroborate these findings; for example, Rock-Eval pyrolysis of several hundred ditch cuttings, core, and outcrop samples indicates that Type I organic matter is by far the most abundant organic matter in the southeast Moncton Subbasin (Macauley and Ball, 1982; Smith, 1985; Brown and Whaley, 1986; and Smith, *et al.*, 1991).

The parallel continuous laminae of the oil shale beds are in many places disturbed by synsedimentary slump folds that result in highly crenulated and contorted laminations (Figure 29a). A thin section of one such bed from the Taylor Village section indicates that the 60 cm thick bed there probably did not slump in mass as the result of a single event. Rather, "zones" a few millimetres in width in this bed overlie one another and show a progressive upward decrease in contortion (Figure 29b). This implies a staged or incremental slumping process perhaps triggered by frequent seismic events.

Loop bedding is another common feature of the oil shale beds (Figure 29b). Loop bedding has been described in other oil shales (Brobst and Tucker, 1973; Gibling, *et al.*, 1985). It is seen as a pinching out of a few laminae, with the underlying and overlying laminae showing no disturbance. It has been ascribed to dewatering along low-angled planes and may be related to compaction or seismic disruption (Smith and Gibling, 1987).

Syneresis cracks are seen in the oil shales at Frederick Brook. The cracks resemble mudcracks but are less regular and tend to radiate from a slightly raised common point. They are not as polygonal as conventional mudcracks, nor are the cracks as wide. Syneresis cracks have been described in many other lacustrine shales, for example, the Upper Triassic Lockatong Formation (Van Houten, 1964), the Eocene Green River Formation (Picard, 1966), and the Devonian Caithness Flagstone Series (Donovan and Foster, 1972). Propagation of the cracks in the shales of Caithness has been related to variations in salinity of the overlying water body.

Sandstone dykes, locally seen in the kerogenous shales or mudstones, have been described from drill core in the Rosevale area (Brown and Whaley, 1986). Surface examples can be seen at low tide in an exposure on the east bank of the Memramcook River at Upper Dorchester (Figure 29c). The outcrop is on the north side of the pier of the old bridge that once crossed the river from Taylor Village. The sandstone dykes there are 15 to 20 cm wide, strike N10°-20°E and dip 80° to 90°W. The dykes are parallel to a prominent set of joints in the kerogenous shales. Both the dykes and joints are offset by later dextral shears that are probably related to the Boudreau Fault (Figure 29c

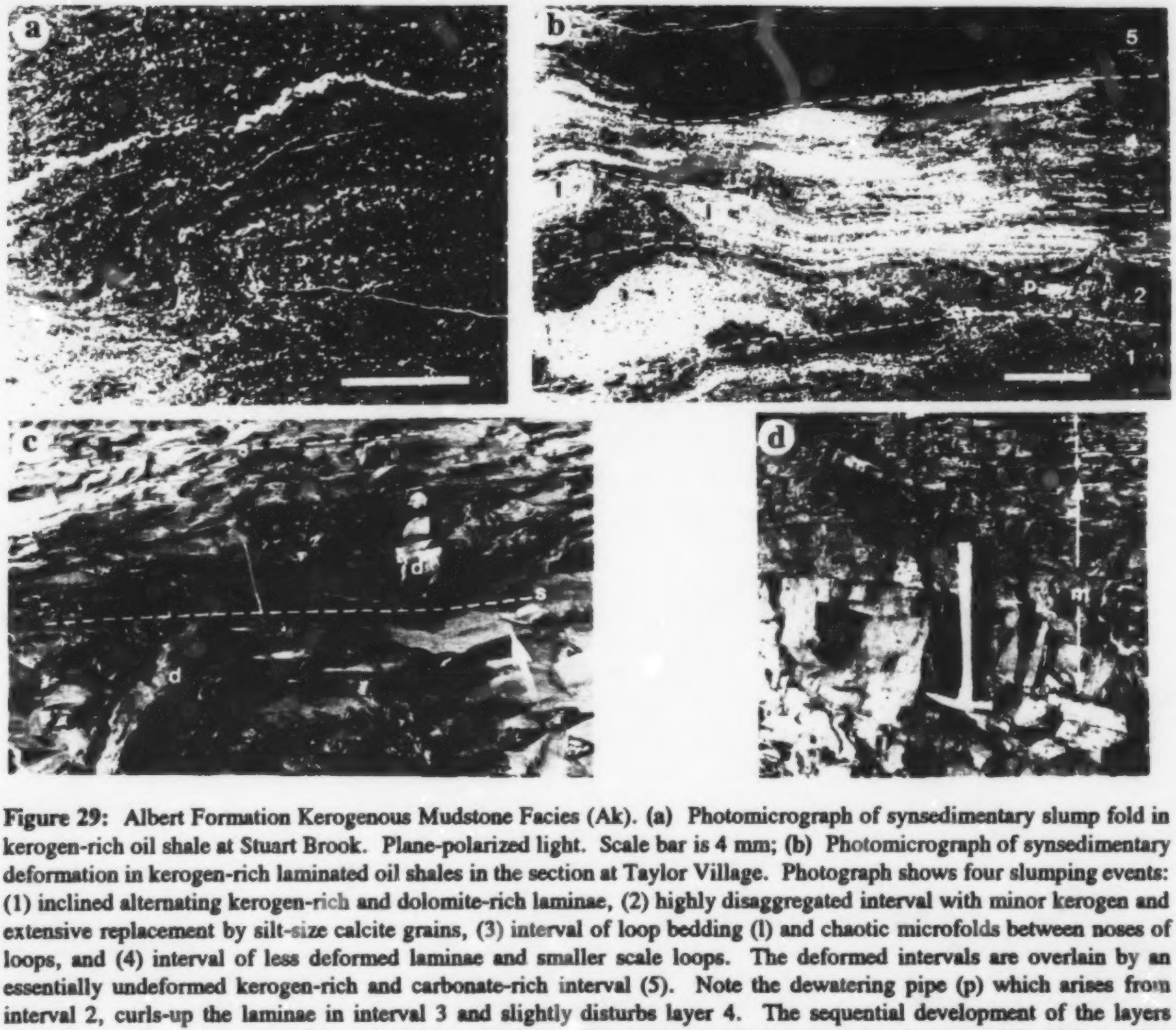

Figure 29: Albert Formation Kerogenous Mudstone Facies (Ak). (a) Photomicrograph of synsedimentary slump fold in kerogen-rich oil shale at Stuart Brook. Plane-polarized light. Scale bar is 4 mm; (b) Photomicrograph of synsedimentary deformation in kerogen-rich laminated oil shales in the section at Taylor Village. Photograph shows four slumping events: (1) inclined alternating kerogen-rich and dolomite-rich laminae, (2) highly disaggregated interval with minor kerogen and extensive replacement by silt-size calcite grains, (3) interval of loop bedding (l) and chaotic microfolds between noses of loops, and (4) interval of less deformed laminae and smaller scale loops. The deformed intervals are overlain by an essentially undeformed kerogen-rich and carbonate-rich interval (5). Note the dewatering pipe (p) which arises from interval 2, curls-up the laminae in interval 3 and slightly disturbs layer 4. The sequential development of the layers suggests a staged process, possibly induced by seismicity. Plane-polarized light. Scale bar is 4 mm; (c) Oblique view of steeply dipping sandstone dykes (d) that strike N20°E and cut shallowly dipping kerogenous mudstone beds at Upper Dorchester. Mudstone and dykes are cut by dextral shears (s) possibly related to the Boudreau Fault. Outcrop is at low tide level and is partially covered by mud. Arrow indicates true north; (d) Massive kerogenous mudstone (m) interbedded with laminated kerogenous mudstone (l) at the Taylor Village section.

and see also page 91). The sand of the dykes is fine medium-grained and is in all cases massive except along the outer margin of one dyke where silt laminae occur parallel to the dyke wall. Clastic dykes are present in chronologically and lithologically similar rocks of the Horton Bluff Formation in Nova Scotia, and are interpreted as resulting from inhibited dewatering and probable overpressuring of sand and silt by well compacted overlying cover rocks (Hesse and Reading, 1978). Injection of the dykes into the Albert Formation, like those in the Horton Bluff, were more than likely triggered by earthquake shocks.

Massive kerogenous mudstone is a minor lithotype of the organic matter-rich facies. It has been described from core sections by Smith (1985) and Smith and Gibling (1987) from the Downing Creek and Frederick Brook areas and from core near Frederick Brook, Dover and Rosevale by Macauley and Ball (1982, plates 1.c, and 3.a). Massive mudstone of this type is also present in the section at Taylor Village (Figure 29d).

The massive kerogenous mudstone beds are light to medium dark brown. Beds range from a few centimetres up to intervals 17 m thick (Macauley and Ball, 1982). The massive beds show sharp or transitional contacts with beds of laminated kerogenous mudstone or oil shale. A transitional contact from laminated to massive kerogenous mudstone is characterized by a gradual decrease in frequency and continuity of kerogen laminae. The massive kerogenous mudstone has no fissility; the rock breaks with a blocky habit. Beds of this type tend to contain more silt than the laminated organic matter-rich beds (Smith, *et al.*, 1991). Intraformational rip-up clasts of laminated kerogenous mudstone are reported in core descriptions from the Frederick Brook and Downing Creek areas (Macauley and Ball, 1982).

Like the other organic matter-rich lithotypes, massive kerogenous mudstone contains dolomite and significant calcite (Table 2). XRD on two samples of core from Frederick Brook (Smith, *et al.*, 1991) suggests the massive beds have no analcime (Table 2). Lack of data prohibits an assessment of whether massive beds are barren of analcime throughout the subbasin. The two XRD determinations from Frederick Brook are, however, not a significant test.

Organic matter in massive kerogenous mudstone is dispersed throughout the mineral matrix. One sample reported in Smith (1985) gives a TOC of 7.26 weight per cent (Table 2). The 16 samples from Frederick Brook show a range in TOC from 2.44 per cent to 9.75 per cent with a mean of 6.06 per cent (calculated from tabular data in Macauley and Ball, 1982, pp. 166-168). Fluorescence microscopy shows the predominantly detrital character of the organic matter; 82 per cent of the macerals are liptodetrinite (Table 2).

Massive kerogenous mudstone beds commonly contain palaeoniscid fish scales. Ostracods are reported from cores at Frederick Brook (Macauley and Ball, 1982, p. 148).

The kerogenous mudstone facies (Ak) contains minor interbeds of grey organic matter-poor shale and mudstone and local beds of sandstone, conglomerate, dolostone, and limestone (see for example the detailed geological map of the Rosevale oil shale area in Brown and Whaley, 1986, Plate 86-162). The organic matter-poor shale and mudstone beds are grey, which serves to distinguish them from the brown-coloured dolomitic kerogenous mud rocks. Bedding thickness ranges from 2 cm to 3 m as estimated from outcrops in the Rosevale area. The grey beds typically contain minor fine-grained calcite, but lack dolomite and visible kerogen laminae. Most beds contain parallel laminae of silt or fine-grained sand. Some mudstone beds are massive. The organic matter-poor mud rocks rarely contain fish scales. Fine-grained plant detritus is quite common in silty mudstones. Some beds show evidence of bioturbation (Brown and Whaley, 1986).

Sandstone beds are quite common in the kerogenous facies west of Rosevale, but are rare at Webster Brook, southeast of Boudreau Village, and near Saint-Joseph. The sandstones typically are light to medium grey and weather light to dark brown. Sandstone beds west of Saint-Joseph are discoloured by dead oil stains.

In most cases, the beds are 2 to 20 cm thick. An outcrop exposing more than 3 m of sandstone occurs at Stuart Brook.

The composition and bedforms of the sandstones are similar to those described above under SANDSTONE FACIES (As), pages 40-43. Most of the sandstones are calcareous and micaceous and vary from quartzose feldspathic arenite to rare beds of lithic wacke. Grain size of individual beds ranges from rarely coarse-grained to more typically fine-grained. In the Stuart Brook section, 30 to 60 cm thick beds are coarse-grained and massive at the base and grade upward to fine-grained and wave ripple-laminated at the top. Intraformational kerogenous mudstone clasts and coarse-grained lithic detritus are present near the base of some beds (Figure 30a). However, many of the sandstone beds are parallel-laminated in the lower part and either cross-laminated or wave ripple-laminated in the upper part. Fine-grained plant detritus is very common in the sandstones, particularly in the parallel-laminated divisions of beds. A piece of tree trunk 12 cm in diameter occurs in a bed on the upper part of Stuart Brook.

There are three types of conglomerate in kerogenous mudstone facies (Ak). First, there are a few beds less than 1 m thick of grey or grey-green polymictic pebble conglomerate along tributaries of Turtle Creek near Rosevale (see core descriptions in this area by Brown and Whaley, 1986). This conglomerate also occurs along the unnamed brook southeast of Boudreau Village and in the subsurface at Frederick Brook (see core descriptions by Macauley and Ball, 1982, p. 99 and p.101). Conglomerate beds of this type contain poorly sorted granules and pebbles of volcanic, plutonic, and metasedimentary rocks in a calcareous sandy matrix. The beds are similar to those described above under Conglomerate Facies (Ac) and probably represent distal parts of coarse tongues that have prograded into the deeper part of the lake.

The second and third types of conglomerate are intraformational mudstone breccia and intraformational sandstone breccia, respectively. Beds of mudstone breccia up to 136 cm thick have been described by Smith (1985) and Macauley and Ball (1982) from core holes at Downing Creek and Frederick Brook. The mudstone breccia comprises angular clasts of massive or laminated kerogenous mudstone or mudstone set in a calcareous silty mud matrix (Figure 30b). A 15 cm thick bed of mudstone-clast breccia in a dolomitic mudstone matrix occurs within oil shales on Stuart Brook 30 m south of the Hillsborough Formation/Albert Formation contact (Plate 92-34).

Intraformational sandstone breccia beds up to 3 m thick have been seen in cores from the Downing Creek and Rosevale areas (Smith, 1985; Brown and Whaley, 1986). Beds of this type contain angular clasts of laminated oil shale or dolomitic kerogenous mudstone in a fine- to medium-grained sandstone matrix (Figure 30c; see also Smith and Gibling, 1987, fig. 3.a). The basal contact of sandy intraformational breccia beds are typically sharp and erosional into underlying mudrocks. The angular intraclasts account for up to 20 per cent of the beds. They are obviously eroded from a partially lithified muddy substratum by a sudden high energy process that sporadically invades this otherwise low energy mud-dominated environment.

Limestone beds ranging in thickness from 5 to 20 cm have been seen in five exposures in kerogenous mudstone facies (Ak) in the southeastern Moncton Subbasin: (1) within kerogenous shale on the upper part of Stuart Brook; (2) about 15 m north of the Caledonia Uplift on Bray Brook, which is 1 km southeast of borehole No. 8, Plates 92-35 and 92-36 (brook is not shown on Plates 92-34 to 92-36); (3) on the east tributary of Frederick Brook, 125 m south of the confluence of its east and west tributaries; (4) 3 beds occur within kerogenous shale on the north

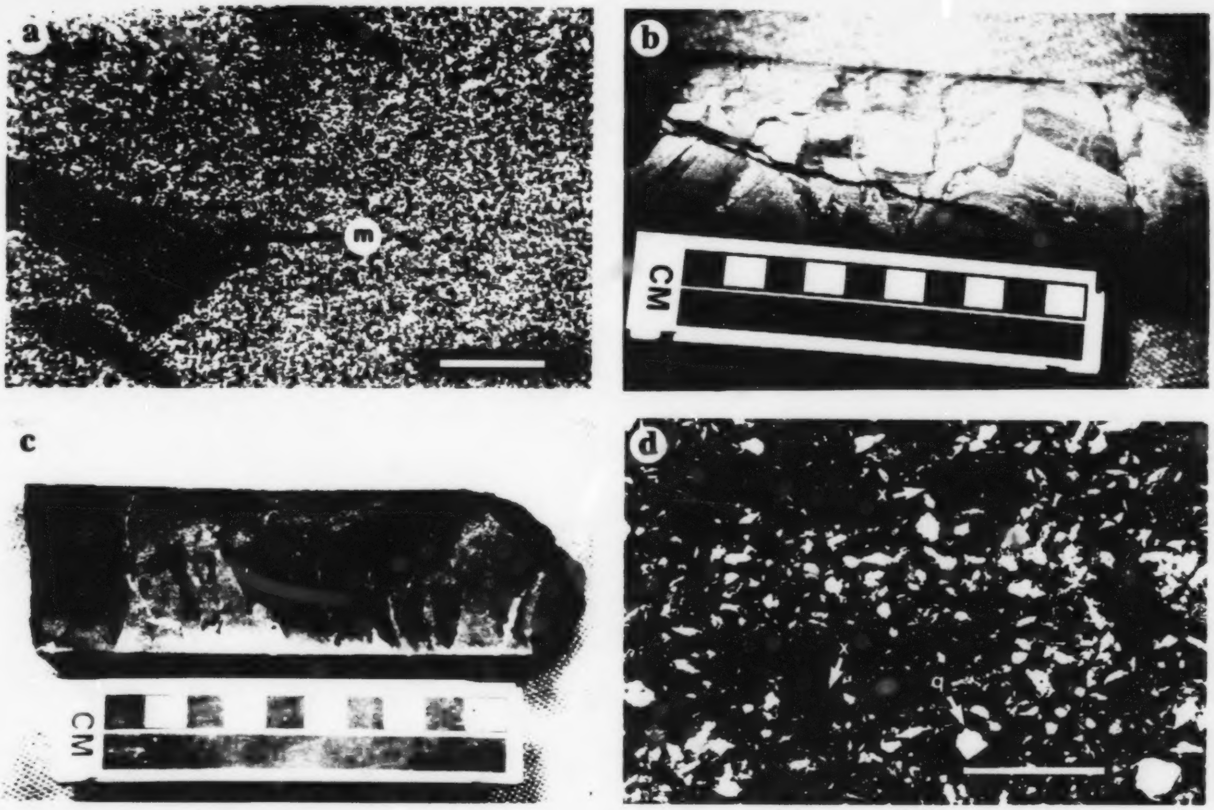

Figure 30: Albert Formation Kerogenous Mudstone Facies (Ak). (a) Photomicrograph of very fine-grained dolomitic sandstone containing intraformational clasts of kerogenous mudstone (m). Outcrop is on unnamed brook southeast of Boudreau Village. Plane-polarized light. Scale bar is 2 mm; (b) Intraformational mudstone breccia from Province of New Brunswick core hole No. 5 in the Rosevale area. See Brown and Whaley (1986) for details; (c) Intraformational sandstone breccia; sandstone matrix contains angular clasts of laminated oil shale. Sample is from Province or New Brunswick core hole No. 5 in the Rosevale area. See Brown and Whaley (1986) for details; (d) Photomicrograph of siliciclastic intraclast grainstone from Bray Brook near Rosevale. Note the angular quartz (q) and the rounded micritic intraclasts or peloids (x). Plane-polarized light. Scale bar is 1 mm.

side of the reservoir on LeBlanc Creek; and (5) a bed occurs within kerogenous shale on a small tributary of LeBlanc Creek, 300 m west of Saint-Joseph. In all cases, the limestone beds are light or medium grey and weather buff to orangish brown. The three limestone beds north of the reservoir at LeBlanc Creek contain oncolites up to 8 mm in long dimension. The limestone at Bray Brook is associated with parallel-laminated mudstone and cross-laminated sandstone. The Bray Brook rock is a siliciclastic intraclast grainstone with about 35 per cent angular siliciclastic grains (Figure 30d). The siliciclastics comprise quartz, quartz-muscovite schist, and felsic volcanic fragments that are graded from coarse-grained to very fine-grained sand. The limestone beds at Stuart Brook, Frederick Brook, and LeBlanc Creek are aphanitic to the unaided eye. At Stuart Brook and LeBlanc Creek the beds contain vague parallel laminae of unknown but probable algal origin. The latter beds contain fractures and vugs filled with tarry bitumen.

Brown to orange-brown-weathering, light to medium grey beds of dolostone are locally present in kerogenous mudstone sequences at Webster Brook, Downing Creek, Frederick Brook, and on the unnamed brook southeast of Boudreau Village. Dolostone beds are also reported from drill cores at Downing Creek and Frederick Brook (Smith, 1985; Smith and Gibling, 1987; Macauley and Ball, 1982). Beds, 2 to 60 cm thick, are seen in outcrop, but Macauley and Ball (1982, p. 98) describe a dolostone bed 40 m thick (drill thickness) in the Frederick Brook area. The dolostone beds range from aphanitic and massive to parallel-laminated. The laminae comprise vague thin continuous to discontinuous layers of organic matter (kerogen) and also siliciclastic layers of silt or fine-grained sand. X-ray diffraction results reported in Macauley and Ball (1982) on 7 samples of dolostone shows a dolomite content of 50 to 84 per cent. The dolostone beds show gradational contacts with interbedded dolomitic kerogenous mudstones (Smith, 1985; Macauley and Ball, 1982). The X-ray data in Macauley and Ball (1982) show a very broad range of dolomite mineral content for dolomitic kerogenous mudstones, dolomitic kerogenous shales and dolostones, thus confirming the highly variable composition and intergradational nature of these lithotypes.

Paleocurrents

Cross laminations in sandstone beds within kerogenous mudstones in the Rosevale area give a mean transport direction toward 336° (Figure 13D, page 38). Although the database at Rosevale is restricted (N = 7), the limited variation in paleoflow indicators suggests a northwest paleoslope. Transport indicators from braided stream deposits on the southeast side of the Moncton Subbasin also indicate a northwest-dipping paleoslope. (See above under CONGLOMERATE FACIES (Ac), page 37).

Depositional Environments

The kerogenous mudstone facies (Ak) is interpreted as a "shallow" to "deep" lacustrine sequence. The sections dominated by microlaminated oil shale with well preserved organic laminae and whole fish fossils evidently represent a very low energy, deep anoxic lacustrine environment (Smith, 1985; Smith and Gibling, 1987). The oil shales show no evidence of bioturbation, suggesting an inhospitable environment for benthos. The rhythmic varve-like character of the laminae may indicate a seasonal or cyclic climatic control on deposition in the deep lacustrine beds.

The widespread existence of synsedimentary folds and local presence of intraformational mudstone and sandstone breccias within the laminated oil shale sections indirectly implies a deep lacustrine setting; for example, formation of mudstone breccias by what clearly seems to be a slumping process suggests considerable bathymetric relief. Sandstones with intraformational clasts of laminated oil shale imply a sudden violent high energy transport mechanism, again possibly indicating substantial bathymetry. However, the absence of graded bedding or Bouma sequences in the sandstone breccias, seems to rule out a density flow mechanism.

The low content of liptodetrinite in the organic matter-rich oil shales indicates limited current activity. At the same time, abundant lamalginite — type I organic matter — and the near absence of types II and III kerogens (Table 2) show the importance of autochthonous organic matter and the insignificance of land-derived higher plant life in the deep lacustrine environment.

Halite is believed to have been a diagenetic mineral in the oil shales locally. At

Frederick Brook, the former existence of halite is interpreted from pseudomorphous cubic calcite. The existence of diagenetic halite in the organic muds indicates very Na-rich alkaline pore waters. If the pore waters were connate or if there were a free exchange of pore fluids with overlying lake waters this would suggest the deep lake environment was alkaline.

The less organic matter-rich sections, that is, those containing mainly kerogenous laminated mudstone, are interpreted as representing a shallower lake environment than that represented by micro-laminated oil shale facies. The kerogenous laminated mudstones contain more siliciclastic silt and less clay and organic matter than oil shale beds; this implies a shallower water setting (Picard and High, 1972, fig. 8). Interbeds of limestone grainstones and wave ripple-laminated siliciclastic sandstones within kerogenous laminated mudstone intervals indicate deposition above fair weather wave base. Algal laminated limestones, algal oncolites within grainstones, and micritic algal mats within kerogenous mudstones, likewise imply a relatively shallow water environment.

The kerogenous mudstones contain abundant liptodetrinite and more sporinite than oil shale (Table 2). This implies an increased significance of land-derived plant debris in the higher energy and shallower lake waters. Locally, large plant stems in sandstone interbeds corroborate this conclusion.

Analcime occurs in kerogenous laminated mudstones and associated laminated mudstones (Table 2), but not in the deeper water lacustrine oil shales. For example, it occurs within organic matter-poor mud rocks at Downing Creek, and in mud rocks associated with shallow lacustrine conglomerate and sandstone lithofacies at Rosevale, Frederick Brook and Boudreau Village (Macauley and Ball, 1982; Smith, 1985). The analcime may be restricted to the organic matter-poor lacustrine mud rocks for two reasons. First, these rocks contain significantly more feldspar (albite) than the deep water organic matter-rich shales. XRD data given by Smith (1985) suggest that the organic matter-poor mud rocks contain 50 per cent more feldspar than organic matter-rich oil shales. If feldspar (albite) is a precursor for analcime — as is argued above — then the restriction of analcime to the near-shore lake environment may be largely controlled by the parent detritus. Secondly, the shallow lacustrine mudstone facies tends to contain more admixed silt and sand and also more coarse clastic interbeds than the deeper lacustrine sequences. The attendant enhancement of porosity and permeability of the shallow water sections would undoubtedly allow greater fluid movement and consequently increase the potential for diagenetic mineral growth. Analcime may be in part a product of this process.

Further evidence of the distinction between "shallow" and "deep" lacustrine environments in the Albert Formation is given in Carter and Pickerill (1985b); Pickerill, *et al.* (1985); Smith (1985); and Smith and Gibling (1987).

CONCLUSIONS

The Albert Formation in the southeastern Moncton Subbasin is divided into six lithofacies: conglomerate facies (Ac), sandstone facies (As), mudstone facies (Am), mudstone/sandstone facies (Ax), evaporite facies (Ae) and kerogenous mudstone facies (Ak). A simplified palinspastic block diagram showing the interpreted architecture of the lithofacies at the close of Albert time is given in Figure 31.

The basal facies of the Albert Formation in this part of the subbasin is largely a widespread unit of grey to locally red mudstones and dolomitic mudstones that is interpreted as distal alluvial fan deposits and organic matter-poor

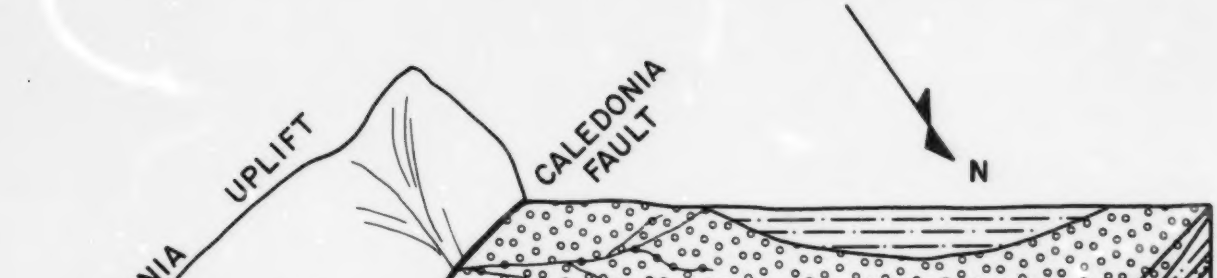

Figure 31: Simplified palinspastic block diagram of Albert lithofacies looking southwest in the southeastern Moncton Subbasin at close of Albert time. Lithofacies patterns: open circles (conglomerate facies), dots (sandstone facies), dash-dot (mudstone/sandstone facies), dash (mudstone facies), dash with oblique bar (kerogenous mudstone facies), and L-shapes (evaporite facies). X = basement complex.

shallow lacustrine mud deposits. In the northern part of the map area, east of Turtle Creek and west of the Stoney Creek Gas and Oilfield, the basal Albert mudstones rapidly change facies into mainly coarse-grained redbeds that apparently represent a fan delta or delta sequence. These coarse sediments occur at progressively higher stratigraphic levels in the Albert from northeast to southwest, implying progradation of the delta from the north throughout Albert time (Plate 92-36 and Figure 31).

The basal mudstones are overlain by an interbedded sequence of mudstones and sandstones of facies (Ax) of marginal and shallow lacustrine origin. Fining-upward and coarsening-upward/fining-upward cycles in the sandstones are interpreted, respectively, as evidence of transgressive and regressive-transgressive cycles of the lake. The close proximity of desiccated mudstones and wave ripple-laminated sandstones gives clear evidence of subaerial marginal to shallow lake settings. In the southern part of the subbasin at approximately this time coarse, subaerial braided stream and subaqueous fan delta deposits began entering the lake. The presence of limestone and organic ostracod- and fish-bearing mudstone interbeds within these conglomerate sections and algal limestone intraclasts in the conglomerates provide convincing evidence of a largely subaqueous origin for the Prosser Brook and Caledonia Mountain/Boudreau Village fan deltas. Both of these fans, along with the fan at Elgin (not shown on Figure 31) remained active throughout Albert time.

The medial part of the Albert is represented by organic matter-rich mudstone facies (Ak), which interfingers with the fans at Caledonia Mountain/Boudreau Village, Prosser Brook, Elgin, and Turtle Creek (Plate 92-36 and Figure 31). The excellent preservation of continuous organic varves, palaeoniscid fishes and articulated ostracods demonstrates very low energy and anoxic bottom conditions in an apparently stratified lake. The medial kerogenous mudstone facies is believed to represent a time at which paleolake Albert was deepest and probably most aerially extensive.

The lithofacies assemblages above kerogenous mudstone facies (Ak) have a lateral and vertical architecture consistent with progressive clastic progradation and infilling of the lake. Sandstone facies (As) in most sections contains evidence of wave-formed ripples and/or storm deposits suggesting that deposition took place mainly above storm wave base. Depending on fetch, this would imply water depths of a few metres or tens of metres. Unidirectional cross laminations, current ripples and rare cross-beds in the sandstones indicate a southern source area for the detritus north of the Caledonia Uplift, but a northern source for the sands along the Westmorland Uplift. The southwestern progradation of the Turtle Creek delta supports the interpretation of a northern provenance. West-directed and southwest-directed paleoflows at Frederick Brook and Mapleton respectively suggest active longshore currents in paleolake Albert.

The uppermost Albert in the southeastern Moncton Subbasin is characterized by a saline lake and playa mudflat surrounded on the south, west, and northwest by an upland braid plain (Figure 31). More than 400 m thickness of rock salt in the axial part of the evaporite facies (Ae) at Weldon clearly indicates a prolonged period of evaporation and salt formation. In this regard, the Albert saline lake and surrounding facies are analogous to those of present day Death Valley or Saline Valley, California (Hardie, *et al.*, 1978, figs. 4-6). The uppermost part of the Albert evaporite facies comprises diagenetic gypsum and glauberite laminae, nodules, and coalesced nodular beds displacing massive and laminated grey mudstones. This subfacies is interpreted as the product of an ephemeral saline lake and saline mudflat and represents the final record of paleolake Albert.

Subsidence in the southeastern Moncton Subbasin during Albert time was controlled by a system of faults along the Caledonia Uplift, including among others the Gordon Falls and Caledonia faults (Plates 92-35 and 92-36 and Figure 31). Whether early displacement on these faults was mainly dip-slip or oblique dip-slip is not well established (see below under INCEPTION OF MONCTON SUBBASIN, pages 86-87). The presence of coarse proximal conglomerates and clear evidence of marginal lake facies adjacent to the Caledonia Uplift demonstrate that the present southern structural margin of the Moncton Subbasin closely approximates the paleo-depositional margin.

The southern subcrop and outcrop extent of the Horton Group (Plate 92-35) and Albert Formation (Plates 92-35 and 92-36) on the south side of the Westmorland Uplift represents an erosional edge of these units. In other words, the Albert lithofacies shown on Plate 92-36 and

Figure 31 on the south flank of the Westmorland Uplift are not basin margin depositional facies. However, the presence of fan delta or deltaic facies east of Turtle Creek and south to southwest paleocurrents in sandstones in the Dover and Boyd Creek areas tentatively suggest the paleo-depositional margin of the Albert Formation in this part of the Moncton Subbasin may have been only a few kilometres north of the present erosional edge.

The northerly prograding Prosser Brook fan-delta and the southerly prograding Turtle Creek fan-delta appear to converge in the area around Berryton (Plate 92-36 and abbreviated logs thereon). If this is true, then Berryton lies near the axis of an Albert depocentre. Likewise, the location of the saline lake and playa evaporites near Weldon can be assumed to mark a paleogeographic low and presumably a depositional locus in this part of the subbasin. The paleoflow data and facies paleogeography strongly suggest the axis of deposition in the southeastern Moncton Subbasin during Albert time was located along a line from Weldon through Berryton and perhaps striking southwest from there toward Portage Vale (Plates 92-35 and 92-36). Corroborative evidence is provided by the apparent increase in thickness of the Albert Formation from north to south towards the interpreted axis of deposition; for example, the apparent thickness at Irving/Chevron Stoney Creek No. 1 well (borehole No. 17, Plate 92-36) is 1 245 m, but the thickness exceeds 1 683 m and 1 443 m at, respectively, Irving/Chevron Hillsborough No. 1 well (borehole No. 19, Plate 92-36) and Imperial Berryton No. 1 well (borehole No. 5, Plate 92-36).

If the above interpretation of the axis of deposition is correct, it implies that the Moncton Subbasin during Albert time was asymmetric; the subbasin had a half-graben shape, with a steep southern escarpment and a more gently-dipping homoclinal northern margin. The interpreted paleogeometry, prior to late Horton strike-slip faulting, is shown on Figure 31.

ALBERT FORMATION SEISMIC FACIES

GENERAL STATEMENT

From 1981 through 1984, Chevron Canada Resources Limited shot about 750 km of Vibroseis seismic reflection on 80 lines in the southeastern Moncton Subbasin (Plate 92-37). Final stack and migrated profiles of these lines are publicly available from the New Brunswick Department of Natural Resources and Energy. The Chevron seismic profiles for Stoney Creek Lease 74-1 (Plate 92-37) are confidential.

Most of the seismic lines shown on Plate 92-37 have been examined as part of this study. Some of the lines have been studied and interpreted in considerable detail. Ten profiles have been selected that show one or more of the following: (1) the types of tectonic features affecting Carboniferous strata, (2) Carboniferous seismic stratigraphy, and (3) seismic facies within the Albert Formation. The ten interpreted profiles are shown on Plates 92-38 to 92-47. A brief description of Carboniferous seismic stratigraphy is followed by an analysis of Albert Formation seismic facies. The early structural evolution of the Moncton Subbasin, in part based on the seismotectonic features, is dealt with below under EVOLUTION OF MONCTON SUBBASIN DURING THE HORTON STRIKE-SLIP CYCLE AND SUMMARY OF SUBSEQUENT STRUCTURAL EVENTS (pages 86-93).

CARBONIFEROUS SEISMIC STRATIGRAPHY

A seismic sequence is a seismic unit characterized by concordant reflections and separated from adjacent seismic sequences by reflection terminations of one of the following types: onlap, downlap, truncation or concordance (Mitchum, *et al.*, 1977a, 1977b). In accordance with accepted practice, seismic sequences are interpreted as depositional sequences of genetically related strata bounded at their top and base by unconformities or their correlative conformities. Using this methodology and the clearly evident reflector truncations (unconformities) in the section and by applying the seismic sequence analysis methods first set forth by Mitchum, *et al.* (1977a, 1977b) and Anstey (1982), and as recently explained and excellently illustrated by Van Wagoner, *et al.* (1988), the Carboniferous section in the Moncton Subbasin can be divided into three seismic sequences from the base to the top: Horton Sequence, Windsor-Hopewell Sequence, and Cumberland-Pictou Sequence. The Hillsborough Formation is seismically concordant with the marine strata of the Windsor Group and is informally assigned to the Windsor Group for the reasons given on pages 8, 17 and 18. Each seismic sequence is further divided into seismic facies. Seismic facies are defined as groups of seismic reflections whose internal configuration, amplitude, continuity, frequency, and interval velocity differ from adjacent seismic facies (Mitchum, *et al.*, 1977a, 1977b; Brown and Fisher, 1977; Anstey, 1982).

The Horton seismic sequence on Plates 92-38 to 92-47 is somewhat arbitrarily subdivided into three seismic facies that approximate the three clastic formations in the Horton Group (Table 1). Accordingly, the seismic facies are labelled "M" for Memramcook Formation, "A" for Albert Formation, and "We" for Weldon Formation. The Boyd Creek Tuff,which occurs within the Weldon Formation, is labelled BC on Plates 92-38, 92-40 and 92-41. Based solely on the character of Horton sequence reflectors, it is not generally possible to objectively subdivide the Horton seismic sequence into seismic facies such that the seismic facies boundaries coincide exactly with formational boundaries. This should not be surprising, knowing that the Horton Group comprises entirely continental clastics that characteristically provide low amplitude, scrappy discontinuous reflectors (Brown and Fischer, 1977; Anstey, 1982; Petterson, *et al.*, 1988). However, from a practical point of view, in order to assess the seismic character of the largely lacustrine strata of the Albert Formation, it is first necessary to seismically separate the Albert from the Horton seismic sequence. The placement of Albert Formation boundaries and all other formation boundaries on seismic profiles (Plates 92-38 to 92-47) was guided by both outcrop control and borehole logs. Lithologic logs from many holes in the subbasin (some holes are shown on Plates 92-34 to 92-36) were employed to pick formation boundaries and depths. Also, there are 26 wells in the Moncton Subbasin for which sonic logs are available and from which velocities for each formation can be determined. The formation depths and velocity data allow an estimation of travel times to formation boundaries, for example, at a point where a seismic line passes across a well. Such travel time calculations have been used to constrain the placement of Albert Formation and other formational boundaries on seismic lines (Plates 92-38 to 92-47). Also, placement of the upper Albert seismic boundary in the southeastern Moncton Subbasin is in part guided by the location of the reflector generated by the Boyd Creek Tuff (Plates 92-38, 92-40 and 92-41).

The Horton seismic sequence is distinguished by reflectors that in most places dip more steeply than reflectors in overlying seismic sequences (Plates 92-38 to 92-47). Also, Horton reflectors, when compared to overlying seismic sequence reflectors, more often occur as steeply dipping, short, high amplitude events, or as reflection-free areas associated with fault zones (see for example reflectors in the positive flower structure between the Belliveau and Forest Hill faults on Plate 92-43, and the reflectors between and adjacent to the Gordon Falls and Lee Brook faults on Plate 92-47).

The Horton seismic sequence is distinguished from the underlying basement complex by the appearance in the Horton of parallel to sub-parallel, continuous to semicontinuous, moderate to high amplitude reflectors (Plates 92-38 to 92-47). Other features that serve to identify the basal Horton sequence boundary are basement reflection terminations (Plates 92-39, 92-42, 92-44 and 92-46), local downlapping clinoforms in the Memramcook Formation (Plate 92-39), and in some places the near absence of reflectors in the basement (Plates 92-38 to 92-42, and 92-45).

The boundary between the Horton and Windsor-Hopewell sequences is marked by erosional truncation of Horton reflectors (Plates 92-40 to 92-45), and by more gently dipping and continuous reflections in the Windsor-Hopewell than in the Horton sequence.

The basal limestone and anhydrite of the marine Windsor Group generate the highest amplitude and regionally most continuous reflection package in the Moncton Subbasin (Plates 92-40, and 92-43 to 92-47). Sonic logs for 7 wells in the Moncton Subbasin give an average velocity of 5 650 m/s for Windsor anhydrite (St. Peter, in preparation). This compares with velocities that range from 4 000 to 4 500 m/s for most strata overlying the anhydrite, thus explaining the prominent positive amplitude reflectors.

On Plates 92-44 to 92-47, the Windsor seismic facies shows diverging reflectors and a gradual increase in time-thickness from south to north off the Caledonia Uplift into the Moncton Subbasin. In concert with this is the apparent presence of two salt pillows (Plate 92-47). The more southerly pillow is the northeastern expression of the salt ridge which hosts the Potash Company of America potash deposit at Penobsquis northeast of Sussex (Plate 92-33). The more northerly salt on the same profile occurs on the footwall side of the Berry Mills Fault. It has not been explored.

In the western part of the Moncton Subbasin the Windsor Group is conformably overlain by Hopewell Group redbeds, clearly evident on Plates 92-43 to 92-47. The Hopewell reflectors, like the Windsor, show divergence from south to north. The Hopewell is characterized in the central part of the subbasin on the south side of the Berry Mills Fault by some very high amplitude, continuous, parallel, to slightly divergent reflectors (Plates 92-43, 92-45 and 92-47). However, further toward the south the Hopewell reflectors become far less continuous; they are irregular and wavy immediately north of the Caledonia Uplift (Plates 92-43 to 92-47). The apparent seismic facies change in the Hopewell is interpreted as the result of proximal alluvial fan and braided stream coarse clastics in the south gradually giving way to more regularly interbedded meandering river sandstones and distal or overbank mudstones in the north. This conclusion is supported by outcrop on the south side of the subbasin and by regional borehole control within the subbasin (Plate 92-34).

The Windsor-Hopewell seismic sequence is superseded by the Cumberland-Pictou sequence. In the eastern part of the subbasin, the Cumberland-Pictou sequence is in most places too thin to be satisfactorily resolved on the industry seismic sections. However, westward from seismic line L91 (Plate 92-43), the basal Cumberland-Pictou sequence boundary is defined on profiles by the highest amplitude and most continuous reflector that lies above the obvious Windsor reflectors (Plates 92-43 to 92-47). The basal Cumberland-Pictou reflector is most evident along the southern part of the subbasin where meandering stream deposits of the Cumberland overlie alluvial deposits of the Hopewell (Plates 92-44 and 92-46). The basal reflector shows a typical lateral in-phase/out-of-phase relationship that is characteristic of unconformities (Mitchum, 1977a, 1977b; Anstey, 1982). On the southern part of seismic line L07 (Plate 92-45) there is tenuous evidence of erosional truncation of short lenticular Hopewell reflectors below the Cumberland-Pictou basal reflector.

ALBERT FORMATION SEISMIC FACIES

In the southeastern Moncton Subbasin the Albert Formation can be divided into four seismic facies. The facies are designated AA, AB, AC, and AD on Plates 92-38 to 92-47.

Facies AA

Seismic facies AA is ubiquitous, occurring on all profiles (Plates 92-38 to 92-47). It is the facies that distinguishes the Albert Formation from other Horton facies.

Facies AA is characterized by high amplitude, continuous to semi-continuous, parallel, regularly cyclic reflectors. The internal configuration of this facies is best displayed on Plates 92-39, 92-42, 92-46 and 92-47. The reflectors on the north part of Plate 92-46 show south-to-north convergence.

The reflector configuration of facies AA suggests the facies is a response to fairly uniformly interstratified sandstones (including conglomerates) and mud rocks. This interpretation is supported by the following: (1) the facies in many places can be followed up-dip to known surface sections of interbedded sandstones and mudstones, and (2) boreholes cutting the facies commonly show interstratified lithotypes; see for example, N.B.G.O. No. 57 and Petro-Canada Dover No.2 wells (Plate 92-39), Irving/Chevron Hillsborough No.1 well (Plate 92-41), and Irving/Chevron Lee Brook No.1 well (Plate 92-46); abbreviated logs for these wells are shown on Plate 92-36.

Correlation of seismic facies and lithologic facies is best demonstrated by comparing the seismic facies on Plates 92-38 to 92-47 with lithologic facies shown on the logs and map of Plate 92-36. From this it is seen that seismic facies AA correlates mainly with interbedded mudstone/sandstone facies (Ax). The seismic facies also includes minor thin interstratified intervals of conglomerate facies (Ac), sandstone facies (As), and kerogenous mudstone facies (Ak).

Facies AB

Seismic facies AB occurs on Plates 92-40, 92-42 and 92-46. The facies is distinguished by short, discontinuous, low to high amplitude reflectors. On Plate 92-46, facies AB reflectors are irregular to wavy. Locally the reflectors become very short and the facies is nearly reflection free (Plate 92-42 and the northern part of Plate 92-46). The external shape of facies AB is in all cases lenticular.

Seismic facies with an internal configuration of short, irregular to wavy reflectors of poor continuity and variable amplitude are commonly interpreted as resulting from terrestrial deposits (Anstey, 1982). More specifically, reflection patterns of this type are interpreted by Brown and Fisher (1977, p. 229) as proximal- to medial-fan facies comprising coarse braided stream or channel-fill conglomerates and sandstones with minor interstratal mudstones. Brown and Fisher's seismic to lithologic facies correlation can be applied very convincingly to the Albert Formation; for example, seismic facies AB can either be traced up-dip to surface conglomerate facies (AC), or be directly correlated with conglomerate-dominated intervals intersected in boreholes on the seismic profiles. The latter is demonstrated by comparing the locations of seismic facies AB in the wells shown on Plates 92-40, 92-42 and 92-46 with the abbreviated lithologic logs of the wells on Plate 92-36.

The correlation of seismic facies AB with conglomerate facies (AC) was utilized in the interpretation of subsurface distribution of conglomerate facies (AC) as shown on Plate 92-36 and simplified on Figure 31. In particular, the lenticular shape of facies AB on Plate 92-42 provides compelling evidence of a large channel or fan-delta (see under CONGLOMERATE FACIES (AC), pages 27-28) prograding into the southeastern Moncton Subbasin from the north.

Facies AC

Seismic facies AC is present on Plates 92-38 to 92-41, and 92-43 to 92-45. The reflectors in this facies are short, lenticular to locally wavy, irregularly spaced and typically of low to moderate amplitude. The marked contrast between reflection patterns in facies AC and AA is well illustrated on Plate 92-39.

Correlation of seismic facies AC with borehole logs and surface exposures indicates the facies is a response to mud rocks with minor interbeds of sandstone or conglomerate. In this regard, facies AC is a seismic expression of Albert mudstone facies (Am). This correlation has been employed in extending mudstone facies (Am) into the subsurface and away from known borehole intersections. A synthesis of the correlations and resulting distribution of mudstone facies (Am) is shown on Plate 92-36 and Figure 31.

Facies AD

Seismic facies AD occurs on Plate 92-40 north of the Boudreau Fault in the Weldon area. On Plate 92-40 it is shown undivided from seismic facies AC (see below).

Facies AD is characterized either by an absence of reflectors or by the erratic appearance of very short reflectors. The external form of the facies is lenticular. Boreholes in the area north of the Belliveau Fault indicate that seismic facies AD is in part a response to Albert evaporite facies (Ae) (see pages 56-63). However, the lithologic log of Imperial Hillsborough No.1 well (borehole No. 20, Plate 92-36) shows that at least locally the upper part of the Albert Formation on the north side of the Belliveau Fault is dominantly mudstone. Accordingly, the reflection-free unit is not a response to a single lithotype, i.e., evaporites. For this reason it is not possible to seismically distinguish evaporites (seismic facies AD for example) from mudstones (seismic facies AC) in this area; therefore, the two facies are grouped as AC + AD on Plate 92-40.

Two observations are notable with respect to the mixed seismic facies AC + AD. First, there is a total absence of reflections in the middle of the unit between the Boudreau and Hillsborough faults. This may indicate a thick (homogeneous?) evaporite section. Secondly, the quantity of short reflectors increases towards the north away from the Belliveau Fault. This may result from an increase in the quantity of lenticular mudstone or sandstone layers toward the north; for example, evaporites change facies to the north, and are completely absent 2 300 m north of the north end of Plate 92-40 at Irving/ Chevron East Stoney Creek No.1 well (borehole No. 18, Plate 92-36).

CONCLUSIONS

An analysis of several hundred kilometres of Vibroseis seismic reflection profiles in the southeastern Moncton Subbasin indicates that there are three distinct seismic sequences in the Carboniferous section. The seismic sequences and their intervening boundaries help substantiate formerly tenuous geological evidence, that there are two angular unconformities within the Carboniferous section.

Seismic facies analysis of the Albert

Table 4: Correlation of seismic facies and lithofacies in the Albert Formation, southeastern Moncton Subbasin, New Brunswick.

ALBERT SEISMIC FACIES	CORRELATED ALBERT LITHOFACIES
AA	Mainly Mudstone/Sandstone (Ax)
AB	Mainly Conglomerate (Ac)
AC	Mainly Mudstone (Am)
AD	Mainly Evaporite (Ac)± Mudstone (Am)

Formation suggests the presence of four distinct reflection facies within the formation. Three of the seismic facies, AB, AC and AD, can be correlated reasonably well with, respectively, conglomerate facies (Ac), mudstone facies (Am), and evaporite facies (Ae) (Table 4). The fourth seismic facies, AA, characterizes most of the Albert Formation and strongly suggests that the formation largely comprises interstratal sandstones (including conglomerates) and mudstones in much of the unexplored subsurface.

Correlation of seismic facies with lithologic facies has greatly assisted in understanding the subsurface distribution of Albert Formation lithotypes. In this regard, the facies interpretations shown on Plates 92-38 to 92-47 were very helpful in constraining the lithofacies geometries shown on Plate 92-36 and on the palinspastic block diagram shown on Figure 31.

EVOLUTION OF MONCTON SUBBASIN DURING THE HORTON STRIKE-SLIP CYCLE AND SUMMARY OF SUBSEQUENT STRUCTURAL EVENTS

GENERAL STATEMENT

A summary of relevant tectonic events in the Late Devonian through Carboniferous evolution of the Moncton Subbasin is given above under TECTONISM IN THE MONCTON SUBBASIN (pages 20-23). The intent here is to briefly describe the important sedimentologic, tectonic and seismotectonic findings arising from the study of the southeastern Moncton Subbasin area that bear on the early basin (Horton Group) history. This is followed by a summary of subsequent structural events to provide a comprehensive interpretation of the present distribution of Albert Formation lithofacies.

INCEPTION OF MONCTON SUBBASIN

The preponderance of evidence from recent studies suggests that during and following the Devonian Acadian orogeny, the northern Appalachians became a site of significant intraterrane and inter-terrane transcurrent faulting (Webb, 1963, 1969; Eisbacher, 1969; McCabe, *et al.*, 1980; Ludman, 1981; Bradley, 1982; Keppie, 1982; Knight, 1983; Leger, 1986; Leger and Williams, 1986; Boehner, *et al.*, 1986; Ferrill and Thomas, 1988; and Hyde, 1989). It was during this protracted phase of Late Paleozoic transcurrent tectonics that the Maritimes Basin and its various subbasins (including the Moncton Subbasin) were initiated and their sedimentary fills subsequently deformed (Fralick and Schenk, 1981; Bradley, 1982; Knight, 1983; Boehner, *et al.*, 1986; Martel, 1987; St. Peter, 1987a; Hyde, 1989). In contrast to the above, other authors have proposed a basin origin by orthogonal rifting and essentially vertical tectonics (Belt, 1968; White, 1972; Ruitenberg and McCutcheon, 1982; and McCutcheon and Robinson, 1987).

It would seem now, that the relevant question is not whether the Maritimes Basin and its substructures were initiated in a wrench setting, but whether the formative stage was transtensional or transpressional? In general, sedimentary basins that form in wrench settings are chiefly the result of crustal extension and sagging along braided fault systems (Wilcox, *et al.*, 1973; Crowell, 1974a, 1974b; Howell, *et al.*, 1980; Mann, *et al.*, 1983). However, local crustal extension and subsequent basin formation can take place in the context of a regional oblique compressive regime; for example, basins several tens to hundreds of kilometres in length have formed in transpressive settings in Sumatra, Venezuela, western Europe, and California (Wilcox, *et al.*, 1973; Crowell, 1974a, 1974b; Reading, 1980; Howells, *et al.*, 1980). In the case of the Moncton Subbasin it is not presently clear whether the basin was initiated through transtension or transpression. The presence of sandstone dykes along north-northeast-trending fractures in the Albert Formation at Upper Dorchester (see page 72) seems to favour an extensional origin. Movements on basin-margin faults following Horton deposition have essentially destroyed outcrop and seismic evidence of initial or growth fault displacements. However, on theoretical grounds, since most basins in wrench settings have a three-part history, what Reading (1980) calls the "strike-slip cycle of transtension — basin filling — transpression", it can be tentatively assumed that the Moncton Subbasin formed via transtension.

MONCTON SUBBASIN MARGINS AND INFILLING BY HORTON FACIES

The southern margin of the Moncton Subbasin during Horton time had approximately the same relationship to the Caledonia Uplift as the present margin. This is implied by the coarse, proximal boulder and cobble alluvial fan or fan-delta conglomerates of the Memramcook, Albert and Weldon formations adjacent to the Caledonia Uplift. The coarse facies give way to finer grained and more distal alluvial, fluvial, or lacustrine facies within a few hundred metres or a few kilometres north of the basement contact (Gussow, 1953; Oldale, 1959; Shroder, 1963; Popper, 1965; Greiner, 1962; McCutcheon, 1978; Pickerill and Carter, 1980; St. Peter, 1982; Carter, 1985; and Pickerill, *et al.*, 1985). The presence of abundant Coldbrook Group detritus in all Horton conglomerates and sandstones, and northwest-directed paleocurrents in the Albert Formation (see pages 37, 46-47 and 77) further support the interpretation of an adjacent southern volcaniclastic source.

Horton rocks on the northwestern margin of the Moncton Subbasin are not as well studied as those on the southeast. Basin-margin Horton strata are covered by Upper Carboniferous Pictou Group beds northeast of Havelock (Plate 92-33). Southwest of Havelock, between the Kierstead Mountain and Belleisle faults, a sequence of coarse conglomerates and sandstones of the Memramcook Formation has a minimum thickness of 700 m. Clast compositions suggest detritus in the alluvial fanglomerates may have been derived from the northwest, which is by paleoflows transverse to the longitudinal axis of the basin (Popper, 1965, p.117). Similarly, on Ridge Brook, 7.6 km north of Havelock (Plate 92-33), angular lithic wacke and slate clasts in Memramcook conglomerate are identical to Ordovician basement rocks exposed immediately to the northwest (St. Peter, unpublished data). The presence of these coarse Memramcook deposits adjacent to the Kierstead Mountain Fault strongly implies that this fault played an active role in controlling subsidence in the northwestern Moncton Subbasin during Horton time.

There are two areas in the central or axial part of the Moncton Subbasin where coarse-grained (proximal?) Memramcook Formation strata are exposed. One is on the north side of the Jordan Mountain basement inlier and the other is on the south side of the Indian Mountain basement inlier (Plate 92-33). Detailed provenance or paleocurrent studies have not been undertaken on these beds to date, but the close association with basement blocks strongly suggests local intrabasinal sources. Clearly, during Memramcook time the Moncton Subbasin was not a simple graben with rising fault-bounded source areas on the southeast and northwest. The coarse proximal facies in the central basin area implies the existence of axial syn-Horton faults and rising intrabasinal basement blocks.

Further evidence of active intrabasinal source areas during Memramcook time is provided by south-southeast-directed paleoflows in the Memramcook type section near Gaytons (see page 12 and Figure 5), where cross-bedded conglomerates and sandstones with abundant plutonic detritus and minor marble of probable Greenhead ancestry imply a source area to the north or northwest. The paleoflows at Gaytons suggest the possibility of a common source both for the fluvial beds there and for the coarser polymictic alluvial fan conglomerates on the south side of the basement sliver at Indian Mountain (Plate 92-33; see also Gussow, 1953, and map-unit 5 of Carr, 1968). In this regard, the basement sliver at Indian Mountain is believed to represent only a small fault slice of a much larger shallowly buried basement ridge. The basement ridge is expressed as a positive magnetic anomaly 5.7 km long by 2.2 km wide on aeromagnetic maps (Geological Survey of Canada, 1960a, 1960b). This basement block is tentatively interpreted as a significant intrabasinal source of Memramcook detritus in the eastern Moncton Subbasin.

In the axial part of the Moncton Subbasin during Albert time, paleocurrent data indicate sediment transport mainly parallel to the long axis of the basin. For example, in the southwest, between Bloomfield and Sussex (Plate 92-33), fill was derived from the southwest (Pickerill and Carter, 1980; St. Peter, 1982; Pickerill, *et al.*, 1985; Carter, 1985). However, in the northeast, between Indian Mountain and Fawcett, paleoflows were from the northeast toward the southwest (St. Peter, 1982). These axially opposed transport indicators, together with northwest-directed Albert paleocurrents in the Elgin area (Plate 92-36 and pages 37 and 46-47), imply a large Albert depocentre in the area between Sussex and Portage Vale (Plate 92-33).

Detailed provenance or paleocurrent data for the Weldon Formation are not available. McCutcheon (1978) reports the existence of proximal/distal facies relationships for Weldon deposits south of Sussex. Clast compositions there suggest a southern Coldbrook Group provenance and consequently paleoflows transverse to the basin margin. In the northeastern part of the subbasin in the Fawcett area (Plate 92-33), Weldon sandstones, like the conformably underlying Albert beds, show southwest-directed axially oriented paleocurrents (St. Peter, unpublished data). This admittedly limited transport data, combined with lithofacies distributions in the Weldon Formation (Shroder, 1963), tentatively suggests a continuation or coincidence of source areas, paleoslopes and depocentres with those previously established in Albert time.

There is no place in the Moncton Subbasin where an unfaulted or otherwise continuous section of Horton Group strata is exposed. Consequently, determinations of thickness from area to area and/or regional variations in thickness are seriously hampered. Estimates of thickness for the Memramcook, Albert, and Weldon formations are given above on pages 13-14, 16 and 19 respectively. Two-way travel time on seismic reflection profiles in the southeastern subbasin suggests a Horton Group thickness of 4 km or more in two areas: (1) between Weldon and Berryton (Plates 92-35 and 92-41), and (2) northwest of Elgin (Plate 92-46). The seismic thickness determinations are based on a sonic velocity estimate of 4 500 m/s. The Horton surface section along the North River near Fawcett, between the Smith Creek and Salt Springs Brook faults (Plate 92-33), is about 3.6 km thick. The Memramcook Formation and upper Weldon Formation are faulted out there, implying a total Horton section thickness of perhaps 5 km or more.

In summary, basin margins and subsidence during Horton time were controlled by a number of faults marginal to the Caledonia Uplift in the southeast (Plates 92-33 and 92-35), and by the Kierstead Mountain and Belleisle faults in the northwest. There were undoubtedly several active northeast-trending faults in the central part of the subbasin. Sedimentation adjacent to basin boundaries and near rising intrabasinal blocks was dominantly transverse to the long axis of the basin. Paleoflows in the central part of the subbasin were mainly longitudinal and directed either northeast or southwest. Present data imply two major depocentres, one in the Berryton/Weldon area (Plate 92-35 and page 81), and the other northeast of Sussex (Plate 92-33). Horton sections of perhaps 5 km thickness in the depocentres give a Famennian through Tournaisian ($13x10^6$ years) post-compaction sedimentation rate of less than 1 mm/a.

INVERSION OF THE HORTON SECTION

Horton deposition ended as the consequence of a major dextral transpressive event. Evidence of this includes: (1) development of braided wrench fault zones, (2) local formation of a strike-slip duplex along the southeastern margin of the Moncton Subbasin (Plates 92-33 and 92-35), (3) formation of en échelon folds associated with strike-slip faults, (4) formation of positive flower structures, (5) intrabasinal basement uplifts, (6) erosion, which has locally resulted in complete removal of the Horton section, and (7) creation of an angular unconformity at the base of the Visean Hillsborough Formation.

It is not possible to give a comprehensive description and analysis of all the bedrock tectonic evidence for inversion of the Horton section in the Moncton Subbasin. Selected evidence is given, mainly from the southeastern part of the subbasin, to demonstrate the style of deformation. Regional faults are shown on Plate 92-33. Additional structural details in the southeastern subbasin are given in plan view on Plates 92-34, 92-35 and 92-36. Seismic cross sections and longitudinal section lines shown on the latter three plates are interpreted on Plates 92-38 to 92-47. A panel diagram synthesizing the interpretation of structural geometry is presented on Plate 92-48.

The fact that most faults in the Moncton Subbasin are long linear features with only local curvature is taken as evidence that they are steeply dipping structures (Plate 92-33). This is confirmed in rare good exposures where faults are exposed. Examples include: (1) the Caledonia Fault on Peck Creek (Plate 92-34), (2) the Taylor Village, Round Hill and Boudreau faults in the section on the east bank of the Petitcodiac River at Boudreau Village (Figure 32a and 32b), (3) the Belliveau and Saint-Joseph faults in the section on the east side of the Petitcodiac River at Belliveau Village, and (4) the Gaytons Fault in the basement aggregate quarry 2 km north of Gaytons (Plate 92-34). Seismic reflection profiles provide supporting evidence that the faults are mainly steeply dipping (Plates 92-38 to 92-47).

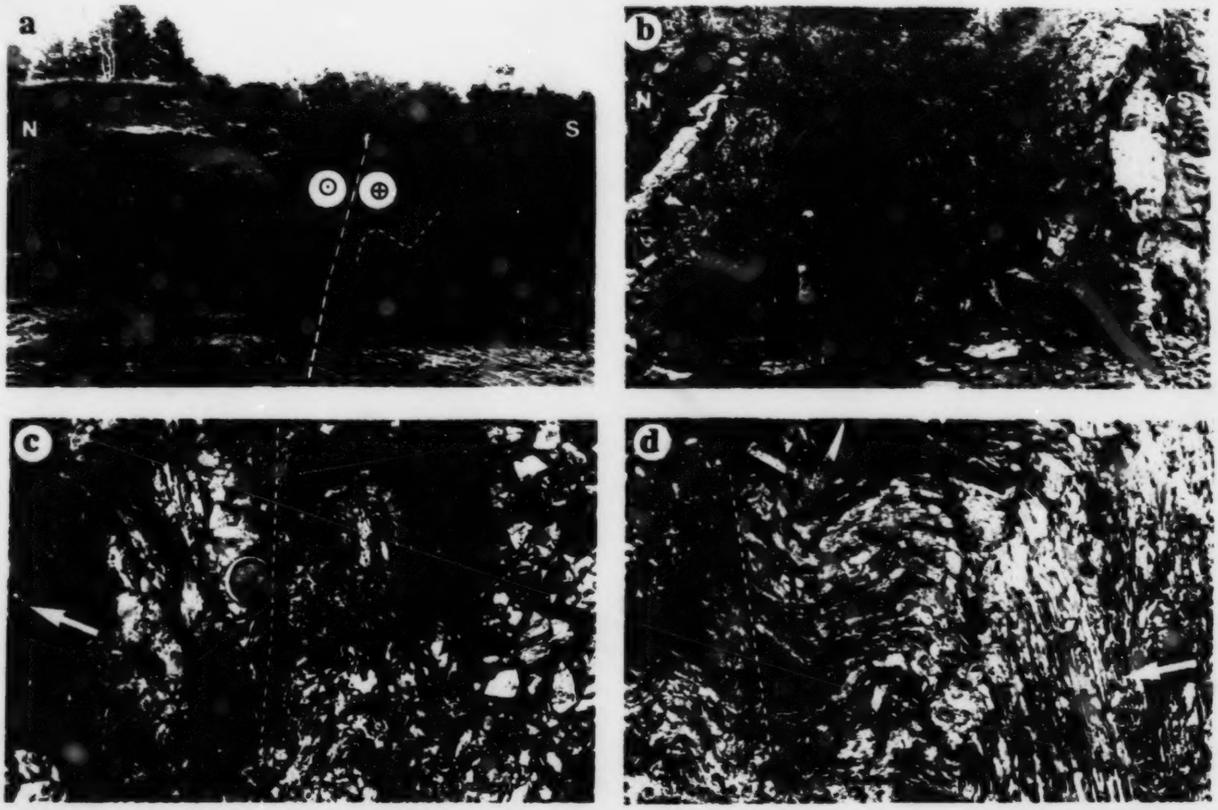

Figure 32: Northeast-trending Faults Cutting Horton Group. (a) Taylor Village Fault (f) in the southern end of the section on the east side of the Petitcodiac River near Boudreau Village. Albert conglomerates on north (N) faulted against Albert sandstone on south (S). ⊕,⊙ = away and toward sense of movenent on fault; relative vertical displacement is unknown; (b) Steeply dipping mélange zone marking the Boudreau Fault in the north (N) -south (S) oriented section on the east side of the Petitcodiac River near Boudreau Village (see Plate 92-34). Fault cuts Albert Formation mudstone/sandstone facies (Ax) at this site; (c) Plan view of S-sense dextral shear folds in Weldon Formation mudstones. Late shears (dotted) have a strike of N70°E and dip 90°. Structure is within the Belliveau Fault zone at the section on the east shore of Petitcodiac River near Belliveau Village (see Plate 92-34). Arrow indicates true north; (d) Plan view of S-sense dextral shear fold in laminated grey mudstone of the Albert Formation. Late shears (dotted) have a strike of N85°E and dip 90°. Fold occurs within the Saint-Joseph Fault zone near the north end of the section at Belliveau Village (see Plate 92-34). Arrow indicates true north.

Faults in the southeastern Moncton Subbasin are conveniently divided into three groups: (1) northeast- to east-northeast-trending, oblique, strike-slip and reverse faults, (2) north- to northwest-trending normal and/or transcurrent faults, and (3) rare northwest-trending reverse faults. Only the northeast- to east-northeast-trending strike-slip faults are involved in inversion of the Horton section. They are described below. The second and third groups of faults are discussed later under FAULTS POSTDATING HILLSBOROUGH FORMATION (pages 93-100).

The northeast- to east-northeast-trending faults show convincing evidence of dextral lateral movement and/or reverse dip-slip movement. Dextral offsets are shown by displaced contacts and by numerous right-handed en échelon megascopic folds (Plates 92-34 and 92-35; see Wilcox, *et al.* (1973) for right-handed and left-handed fold definitions). Further evidence of right-lateral offset is shown, for example, by mesoscopic S-shaped folds with northeast- to east-striking and shallowly to steeply plunging hinge lines along the Belliveau and Saint-Joseph faults (Figures 32c and 32d), and by displacements on sandstone dykes cut by the Boudreau Fault (Figure 29c, page 73).

Reverse displacements on northeast-trending faults are shown by locally overturned bedding in Horton strata and by juxtaposition of older rocks over younger ones; for example, the Albert Formation on Frederick Brook between the Edgetts Landing and Dorchester Faults shows a gradual increase in dip from north to south (Plate 92-34) for a distance of about 130 m north of the Dorchester Fault, where bedding dips range from vertical to 80° overturned towards the south. The change in bedding attitudes associated with the reverse faulting suggests the presence of a drag fold of the Albert beds over the Enragé and Hillsborough conglomerates to the south. From this relationship it is obvious that the latest reverse movement on the Dorchester Fault post-dates the Enragé Formation. However, the steep dip of the Albert beds in contrast to the subhorizontal disposition of the Hillsborough and Enragé conglomerates implies that most of the displacement pre-dated the Hillsborough unconformity. Further evidence of north-over-south reverse movement on the Dorchester Fault is provided farther to the southwest where basement rocks on the north are faulted against Hillsborough conglomerates on the south (Plate 92-34, see also McLeod, 1980).

Reverse dip-slip displacement of Horton Group strata is suspected but unsubstantiated on the Caledonia Fault. Circumstantial evidence of this is seen in an exposure of Albert Formation mudstone on the easternmost tributary of Prosser Brook (Plate 92-34). There, a shear zone with a strike of S85°E and dip of 65°N has slickensides with a pitch of 80°E. The slickensides may indicate the Albert mudstones have been reverse faulted from the north over the basement rocks that lie immediately to the south. This interpretation could account for the absence of Memramcook Formation exposures on the north side of the Caledonia Fault in this area.

Reverse offset on the Prosser Mountain and Belliveau faults is indicated at Prosser Brook by the juxtaposition of basement rocks on the north against Hillsborough strata on the south (Plate 92-34). On seismic line L91 (Plate 92-43) opposing senses of reverse displacement on the Belliveau and Hillsborough faults result in the formation of an intervening syncline, which gradually widens with depth. It is apparent on line L91 that most of the reverse displacement on the Hillsborough and Belliveau faults predated deposition of the Hillsborough Formation.

Reverse south-over-north movement on the Pollett River Fault is apparent from north-younging overturned Albert beds on the north side of the fault at Webster Brook, Pollett River, and Pleasant Vale (Plate 92-34). South-side-up displacement on this fault is also implied by the fact that older Memramcook rocks lie on the south hanging wall side (Plates 92-34 and 92-35).

In plan view there is a major concave northwest-facing bend in the Gordon Falls and Pollett River faults in the Elgin area (Plates 92-34 to 92-36). Since these faults show dextral offset, the bend is a restraining bend (Crowell, 1974a). On the north side of the Pollett River Fault and on the northeast arm of the bend there are three lenticular fault blocks bounded by the Pollett River, Pleasant Vale, Mapleton, Elgin, and Parkindale faults (Plate 92-35). The lenticular shape of these blocks and their relationship to the bend resembles what Woodcock and Fischer (1986) describe as a contractional strike-slip duplex. This interpretation of fault geometry and kinematics is supported by the repetition of lithologic facies in the Albert Formation within the blocks (Plate 92-36), and by the presence along strike to the northeast of positive flower structures. The presence of positive flower structures (see Sylvester and Smith (1976), and Harding (1985) for definition and examples) is interpreted on seismic profiles L91 and L5Y (Plates 92-43 and 92-44). The surface shape of the duplex and its vertical geometry interpreted as a positive flower structure is strikingly similar to that postulated by Woodcock and Fischer (1986, fig. 12b).

Analysis of all available seismic reflection lines in the southeastern Moncton Subbasin shows that dextral reverse displacements on the northeast-trending faults have resulted in formation of classic positive flower structures (Sylvester and Smith, 1976; Harding, 1985). Initial interpretation of seismic profiles and collation with outcrop evidence suggests there are three strike-slip reverse fault zones. Each zone has its associated positive flower structures. The most southerly zone includes the following faults: Dorchester, Edgetts Landing, Taylor Village, Caledonia, Round Hill, Boudreau, and Hillsborough. The positive flower structure related to these faults is interpreted on Plate 92-40. The same flower structure can be seen on other north-south seismic profiles crossing the fault zone (Plate 92-37). The second fault zone comprises Prosser Mountain, Belliveau, Saint-Joseph, and Gowland Mountain faults. An axial push-up associated with the positive flower in this second zone is defined by the basement ridge striking northeast from Little River to Prosser Brook (Plates 92-34 and 92-35). The Saint-Joseph Fault may represent the only presently recognizable fault in a contractional imbricate fan (see Woodcock and Fischer (1986) for definition) at the northeast end of this second zone. The third and most northerly fault zone includes the Gordon Falls, Pollett River, Pleasant Vale, Mapleton, Elgin, Kay Settlement and Lee Brook faults. The positive flower structure related to this fault zone is associated with the restraining bend and the contractional duplex described in the previous paragraph.

Based on the quality of available seismic reflection profiles, it seems that the third fault zone dies out in the area around Berryton (Plate 92-35); for example, the Parkindale and Forest Hill collector faults are not apparent on line L83Y (Plate 92-37). Also, there is considerable doubt regarding the presence of the Gordon Falls Fault on L83Y. The fact that the positive feature associated with the fault zone "merges" with a large syncline east of Berryton (Weldon Syncline of Gussow, 1953) supports the interpreted termination of the fault zone. However, the interpreted termination of the zone should be tempered with the understanding that strike-slip faults are often difficult to "pick" on seismic profiles and even more difficult to correlate with certainty (Tucker and Yorston, 1973; Coffeen, 1978; and Anstey, 1982).

The amount of movement on individual northeast-trending faults in the southeastern Moncton Subbasin is very difficult to ascertain. The virtual certainty that displacements on many of these faults was oblique (either reverse dip-slip or normal dip-slip), rather than pure strike-slip, further complicates the problem. For instance, if the duplex model interpreted for the fault geometry northeast of Elgin is correct, then the repetition of Albert conglomerate facies (Ac) (see Plate 92-36) suggests dextral lateral offset on the Pollett River Fault of perhaps 10-20 km. If, on the other hand, the facies repetition is largely controlled by reverse dip-slip, then the lateral displacement would be much reduced.

It seems quite likely that significant normal dip-slip has occurred on the Gordon Falls, Prosser Mountain, Boudreau, Caledonia, and Dorchester faults. Evidence of normal faulting associated with the Gordon Falls/Pollett River fault zone is seen in the Albert Formation along the Pollett River. There, conglomerates and graded sandstones are offset by minor faults which define classic horst and graben structures (Figure 33a). Early normal down-on-the-north and/or later reverse up-on-the-south displacement of basement rocks along the Gordon Falls Fault is greater than 700 m (Plate 92-44). On seismic line L65YA (Plate 92-40) the dip-slip (normal or reverse?) offset of basement rocks on the steeply dipping Boudreau Fault is about 1.5 km, and on the Dorchester Fault about 800 m. Therefore, from the above estimates it appears that lateral movements on the northeast-trending faults are in the range of a few hundred metres to a few tens of kilometres. Dip-slip normal or reverse displacements may be 2 km or greater on some basin-margin faults.

Displacements on the northeast-trending faults are largely pre-Hillsborough in age. This is best seen by examination of map Plates 92-34, 92-35 and 92-36 and interpreted seismic profiles (Plates 92-38 to 92-47) from which it is immediately apparent that the Horton rocks are folded, and that fault offsets are much greater than in the shallowly dipping overlying Windsor/Hopewell sequence. Displacements on the northeast-trending faults that are younger than the Hillsborough Formation are discussed in the next section of this report.

From the above discussion it is apparent that Horton sedimentation terminated as a result of a dextral transpressive faulting event that lead to braided wrench fault zones with associated en échelon right-handed folds, duplex structures and positive flower structures. A consequence of this structural inversion of the Horton section was ensuing erosion. Over the most rapidly rising blocks erosion resulted in the complete removal of the Horton section. This is evident for example where basement is exposed at Jordan Mountain and Gaytons (Plate 92-33) and over the basement ridge between the Prosser Mountain and Belliveau faults (Plates 92-34 and 92-35). The combined effect of transpression and erosion resulted in folding and segmentation of the Horton section. The thickest sections are preserved in doubly plunging synclines such as that between Weldon and Berryton (Plates 92-35 and 92-36). The thinnest preserved Horton sections occur over intervening arches such as that at Parkindale (Plates 92-35 and 92-36). The end of the Horton strike-slip cycle is indicated by Hillsborough conglomerates, which unconformably overlie both the basement and the incompletely eroded structurally preserved remnants of the Horton sections.

FAULTS POSTDATING HILLSBOROUGH FORMATION

Deformation of the Albert Formation did not end with completion of the Horton strike-slip cycle. As indicated above under INVERSION OF THE HORTON SECTION, pages 89-93, Albert rocks are cut by three groups of faults: (1) northeast- to east-northeast-trending, oblique, strike-slip and reverse faults, (2) north- to northwest-trending normal and/or transcurrent faults, and (3) rare northwest-trending reverse faults. Consequently, to more fully appreciate the present distribution of Albert lithofacies, it is necessary to understand the displacements and relative ages of the movements on the three fault groups that post-date the Hillsborough Formation.

Northeast-trending Faults

In the preceding section it was shown that the major northeast-trending faults in the Moncton Subbasin have significant displacements that pre-date the Hillsborough Formation. Most of these faults also have demonstrable movements that post-date the Hillsborough Formation. For example, in the southeastern Moncton Subbasin, basal Windsor seismic reflectors are broken by

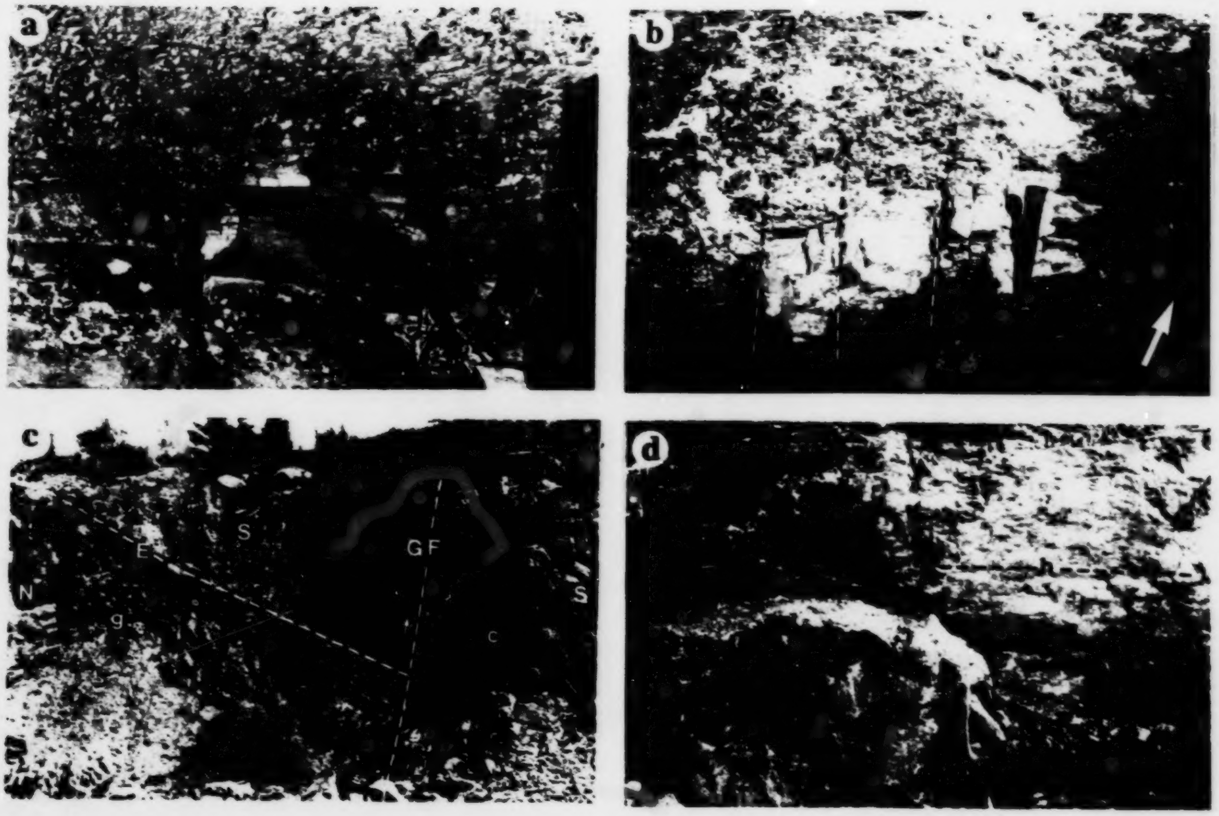

Figure 33: Faults in Southeastern Moncton Subbasin. (a) Albert Formation conglomerate and graded sandstone at the Pollett River cut by minor normal faults. Photograph taken looking west; (b) Plan view of northwest-trending, steeply dipping minor sinistral faults (dashed lines) on the Pollett River displacing contact between conglomerate (above) and sandstone (below). Arrow indicates true north; (c) Southeastern wall of the Gaytons quarry showing the Gaytons Fault (GF) with basement granite (g) on the north (N) reverse faulted over massive Memramcook conglomerate (c) on the south (S). Gaytons Fault offsets earlier fault (E), which has thrust steeply dipping Memramcook strata (s) over the fractured basement granite; (d) Section looking south showing the surface of the Gaytons Fault at the quarry shown in Figure 33c. Fault strikes N80°E and dips 80°N. Two generations of slickensides have pitches of 00° (h) and 80°NW (v).

many faults. Offsets, however, are generally restricted to a few tens or hundreds of metres. The Prosser Mountain and Dorchester faults may be exceptions; in both cases, basement rocks on the north are juxtaposed against Hillsborough or younger rocks on the south. The Pollett River, Parkindale, Forest Hill, Dorchester, Edgetts Landing, Boudreau, and Taylor Village faults all have minor post-Cumberland displacements (Plate 92-34). The Pollett River Fault cuts the Enragé Formation south of Parkindale. Both the Parkindale and Forest Hill faults break the basal Cumberland reflector on seismic line L5Y (Plate 92-44). Further evidence of late movement on the Parkindale Fault is shown along the Kennebecasis River where typically sub-horizontal Boss Point beds dip north at 70° (Plate 92-34).

The Boss Point Formation is displaced by the Dorchester Fault. This is demonstrated by: (1) an obvious offset on the basal Cumberland seismic reflector (Plate 92-40), (2) vertical Boss

Point strata at the old Dorchester copper deposit 1 km southeast of Woodhurst (Plate 92-34), and (3) a known shear zone in Boss Point rocks about 60 m north of the road leading east from Albert Mines. This shear zone was defined by an electromagnetic conductor survey and by drilling carried out in 1987 by John Hartt of Maritime Groundwater as the result of his successful search for potable water for the village of Hillsborough (J. Hartt, personal communication, 1991).

Late Carboniferous movement on the Edgetts Landing, Boudreau, and Taylor Village faults is evident from seismic reflection profiles and also from escarpments in Boss Point rocks on the ridge east of Boudreau Village (Plate 92-34).

Although most of the displacement on northeast-trending oblique-slip faults in the southeastern Moncton Subbasin largely pre-dates the Hillsborough Formation, this is not the case for many faults in the northwestern part of the subbasin. For instance, the faults between and associated with the Berry Mills and Smith Creek faults (Plate 92-33) show substantial displacements of Windsor Group and younger rocks. The Berry Mills/Smith Creek fault zone is a braided dextral transpressive network with associated positive flower structures, and is analogous to the fault zones in the southeastern subbasin (St. Peter and Fyffe, 1990). However, significant movement in this zone is later than in the southeast as shown by greater than 2 km of reverse dip-slip offset on the basal Windsor reflector along the Berry Mills Fault, seen on seismic line L29Y (Plate 92-47).

The Berry Mills Fault links up with the Kennebecasis Fault zone southwest of Sussex (Plate 92-33). The same fault system continues along strike to the southwest for 100 km where it is seen to shear the Lepreau Formation. Folds and cleavage in the Lepreau redbeds have been interpreted as compressional structures related to wrench faulting (Stringer and Lajtai, 1979). The Lepreau Formation has tentatively been dated from trace fossils as Late Triassic or Early Jurassic (Sarjeant and Stringer, 1978), but palynological analysis of the Lepreau Formation indicates a Lower Carboniferous (late Visean) age (Stringer and Burke, 1985, p. 4). Further details on northeast-trending faults throughout the Moncton Subbasin is the subject of a forthcoming Ph.D. thesis by W. Nickerson of Memorial University of Newfoundland.

Northwest-trending Normal and/or Transcurrent Faults

The second group of faults cutting the Albert Formation and younger Carboniferous rocks are north- to northwest-trending normal and/or transcurrent faults (Plates 92-33 to 92-36). The major faults in this group are very poorly exposed; their location and sense of offset are for the most part deduced from apparent displacements on contacts and/or map relationships. The Memramcook East Fault (Plates 92-34 to 92-36) is an exception; its surface location and westerly dip is fixed by trenches and drill holes in the Memramcook East barite occurrence (Hamilton, 1968), and by seismic reflection lines L41Y and L70A (Plates 92-34, 92-37 and 92-38). On line L70A down-to-the-west normal dip-slip of basement rocks on the Memramcook East Fault is interpreted to be about 700 m.

Three northwest-trending faults in the Prosser Brook area displace the Caledonia Fault, the Boudreau Fault, and the Hillsborough Formation (Plate 92-34). The sense of offset on these faults suggests the possibility of minor lateral slip. In fact, if the three faults are vertical or nearly vertical, then dextral and sinistral offsets are assured. The assumption of steep dips on these northwest-trending faults is consistent with those seen on steep minor faults cutting the Albert Formation at the Pollett River. There, sinistral offsets of a few centimetres are observed on several northwest-trending wrench faults (Figure 33b). Other northwest-striking, steeply dipping fault zones in southwestern New Brunswick have been described by Ruitenberg (1967), Stringer and Burke (1985), Gates(1989), and Stringer, *et al.* (1991). The best known of these is the Oak Bay Fault along the Maine and New Brunswick border. Gates (1989) has argued that the Oak Bay Fault has a sinistral strike-slip displacement of 2 km and a normal dip-slip offset of 2 km on the Late Silurian Oak Bay Formation. Gates (1989) further states that the Oak Bay Fault displaces a lava flow in the Late Devonian Perry Formation; Stringer, *et al.* (1991), on the other hand, say the fault does not displace the Perry lava. Regardless, it seems likely that most northwest-trending faults in southern New Brunswick had an oblique dip-slip sense of movement, and that some of these Acadian structures were reactivated during the Carboniferous.

Evidence that the northwest-trending steep faults are related to northeast or east-northeast extension is provided by the intrusion of two felsic dykes on Peck Creek. The dykes occur immediately south of the Taylor Village Fault (Plate 92-34). One dyke is about 1 m wide, the other about 2 m wide; both strike northwest and dip steeply northeast. In addition to providing an indication of northwest-trending normal faults, east-northeast-trending shears that cut the dykes give conclusive evidence of two periods of late faulting (see below and Figure 34a to 34c, page 98).

It is not known for certain if any of the northwest-trending faults pre-date Hillsborough deposition. In this regard, the fault west of Frederick Brook, defining the contact between Albert Formation and basement rocks, shows circumstantial evidence of displacement synchronous with Albert deposition (Plate 92-36). Surface geology and drill holes in the Albert beds show a facies change from coarse proximal conglomerates near the basement to distal kerogenous mudstones and shales less than 1 km to the east at Frederick Brook. The facies change could indicate syn-sedimentary down-to-the-east normal offset on this fault.

Movement on the northwest-trending faults that post-dates Hillsborough deposition is well established from map patterns and deformed Hillsborough strata; for example, note the 60° dip of Hillsborough conglomerate on the east side of the normal fault that lies east of Frederick Brook between the Edgetts Landing and Taylor Village faults.

The most significant period of movement on the northwest-trending faults is believed to have been during Hopewell (Namurian) time. Evidence is provided by the stratigraphic relationship of Hopewell beds in the Sackville Subbasin to a time-equivalent unconformity in the southeastern Moncton Subbasin. The Sackville Subbasin lies southeast of the Moncton Subbasin (Figure 3, page 7). The basins are in contact across the Memramcook River Fault (Plates 92-34 to 92-36). In the Sackville Subbasin, Hopewell Group rocks of the Maringouin and Shepody formations (Table 1, page 9) form a sequence about 300 m to 1 500 m thick (Gussow, 1953; Martel, 1987). Maringouin and Shepody rocks are not present in the southeastern Moncton Subbasin; their stratigraphic position is assumed by an erosional angular unconformity at the base of the Enragé Formation (Table 1 and Plate 92-34). The apparently rapid subsidence of the Sackville Subbasin at this time is believed to have been accommodated by normal displacements on the Memramcook River Fault on the western side of the Sackville Subbasin, on the Port Elgin Fault on the eastern end of the Sackville Subbasin (Martel, 1987), and by normal reactivation of the Taylor Village, Boudreau, and Dorchester faults on the northern margin of the Sackville Subbasin. The period of normal faulting during Hopewell time was accompanied by erosion and the formation of an angular unconformity on the adjacent upthrown Moncton Subbasin and Westmorland Uplift.

Minor late movement is known on the Memramcook River Fault (Plates 92-33 and 92-34). McLeod and Ruitenberg (1978) mapped northwest-oriented subsidiary shears related to this fault in Boss Point strata near the mouth of the Memramcook River.

Northwest-trending Reverse Faults

The third group of faults that have locally cut Carboniferous rocks are northwest- or west-northwest-striking and northeast-dipping reverse faults. These faults have only been documented in the southeasternmost part of the Moncton Subbasin (Plates 92-34 to 92-36). The best exposed fault in this group is the Gaytons Fault (Figure 33c). It is seen on the southeast face of the Gaytons quarry 2 km north of Gaytons (Plate 92-34), where porphyritic basement granite on the north is reverse-faulted over Memramcook conglomerates and sandstones on the south. Slickensides on one fault plane in the zone indicate three different movement vectors: two slickenside directions are subhorizontal, while the third and probably latest has a pitch of 80°NW (Figure 33d). The latter is interpreted as evidence of late reverse up-on-the-north offset on the Gaytons Fault. It should be noted that the main north-dipping fault in the Gaytons Fault zone is seen to offset an earlier reverse fault (strike N35°E, dip 40°SE) which has thrust Memramcook strata northwestwards over basement granite (Figure 33c). This earlier fault is consistent in attitude and displacement with the first group of faults (i.e., the major northeast-oriented, dextral strike-slip and oblique-slip structures) described above.

Another northwest-striking reverse fault is the La Montagne Fault (Plates 92-34 to 92-36). It is exposed 3 km northwest of Saint-Joseph in a small stream bed where basal red and grey mudstones of Albert mudstone facies (Am) are faulted against medial kerogenous mudstone facies (Ak) (Plate 92-36).

In the Frederick Brook and Peck Creek areas there are also northwest-trending reverse faults (Plates 92-34 to 92-36). The best example is a reverse fault on Peck Creek, which cuts the two felsic dykes described above and shown on Figure 34a. The fault is believed to be part of the same fault as that seen 1 km farther west between the Taylor Village and Round Hill faults (Plate 92-34). Both segments of this northwest-oriented fault are seen in outcrop, and in both the fault dips at moderate angles northeast. Correlation of the fault across the Taylor Village Fault is taken as evidence of anomalous sinistral movement on the latter structure, that is, the northwest reverse faults are cut by reactivation of the northeast-trending wrench faults. Tectonic fabrics seen in the felsic dykes support this interpretation; for example, in outcrop the dykes are seen to be cut by two sets of brittle shears that are approximately at right angles to each other. Movement on the shears has resulted in disaggregation of the dykes into irregular to ellipsoidal blocks (Figure 34a). In thin section the two shear fabrics in the dykes have given rise to fractured and crushed quartz and feldspar phenocrysts (Figures 34b and 34c). Some strained quartz phenocrysts have recrystallized into unstrained polygonal mosaics. Calcite veins that have formed along the later S_2 fractures have later been sheared (Figure 34b) demonstrating a prolonged history of movement.

The fault defining the contact between basement rocks and the Albert Formation west of the headwaters of Frederick Brook is believed to have a component of late reverse slip. [See above on page 96 where it is argued that this fault may have had an earlier normal displacement synchronous with Albert deposition.]

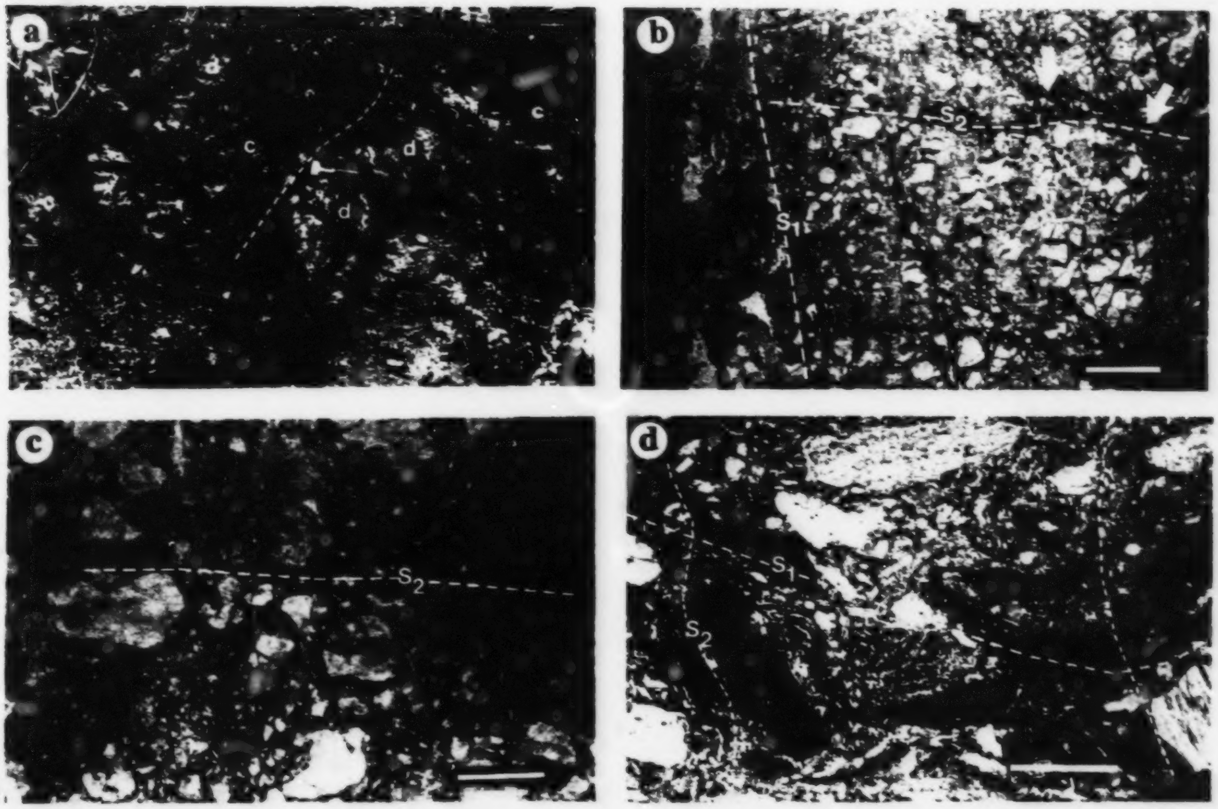

Figure 34: Faults in Southeastern Moncton Subbasin. (a) Section looking southwest shows sheared felsic dyke (d) cutting Albert polymictic conglomerate (c) on Peck Creek. Dyke comprises irregular to ellipsoidal blocks (lighter grey) in a sheared sedimentary tectonic "matrix" (darker grey). Early shears (dotted) strike S30°E and dip 40°NE; (b) Photomicrograph of cataclastic felsic dyke on Peck Creek showing fractured quartz (q), k-feldspar (k), and plagioclase (p) phenocrysts. S_1 fractures cut the sample from top to bottom; S_2 fractures trend from left to right. Note the later fractures are filled with calcite some of which is sheared (arrows). Plane-polarized light. Scale bar is 3 mm; (c) Detail of Figure 34b showing calcite vein along S_2 cutting elongated and fractured phenocrysts. Plane-polarized light. Scale bar is 1 mm; (d) Photomicrograph of polymictic Albert conglomerate from the fault zone defining the contact with basement west of Frederick Brook. Conglomerate shows two tectonic fabrics: a preferred dimensional orientation of the clasts from left to right (S_1) and a later rotation of the larger clasts shown by dotted lines (S_2). Plane-polarized light. Scale bar is 4 mm.

Reverse movement is interpreted from the fact that Albert strata on the east side of the fault dip and young towards the fault suggesting that the beds are buckled into a macroscopic drag fold. A thin section from a grab sample of conglomerate in the fault zone provides clear evidence of two fabrics (Figure 34d). The earlier shear fabric is defined by a preferred dimensional orientation of clasts, while the later fabric is evident from rotation of the larger clasts. It is implied from this that there were two periods of movement on the fault.

The northwest-trending reverse faults are interpreted to be younger than the north- to northwest-trending steep normal and/or transcurrent faults. This is based on two observations: (1) shearing along the felsic dykes on Peck Creek, and (2) late drag folding and reverse displacement on the previously "normal" fault along the basement contact west of Frederick Brook.

The northwest-trending reverse faults are younger than the Horton age displacements on the group 1 northeast-trending oblique strike-slip faults. This is convincingly seen by fault offset relationships along the Gaytons Fault (see above, page 97).

The northwest-trending reverse faults around Frederick Brook and Peck Creek are themselves offset by late movement on the northeast-trending strike-slip faults that displace Cumberland and younger strata (Plate 92-34). As noted above, the northwest-trending reverse fault that shears the dykes at Peck Creek is interpreted to be sinistrally displaced by later movement on the Taylor Village Fault (Plate 92-34). Late sinistral movement is also indicated on the Caledonia Fault 14 km west of Peck Creek. There, along the eastern-most tributary of Prosser Brook, an outcrop of Albert Formation mudstone contains two shear fabrics. The later fabric has a strike of N35°E and a dip of 60° NW. The late shear surfaces sinistrally offset earlier east-striking shears. Slickensides on the late shears pitch 25°NE suggesting largely transcurrent late movement.

The northwest to west-northwest orientation of the reverse faults implies a southwest or south-southwest maximum compression direction during their formation, an approximately 90° clockwise change in maximum stress orientation from that operative during formation of the northeast dextral oblique faults. This change in stress field is reflected by sinistral reactivation of the earlier dextral northeast-trending strike-slip faults. As described above, the best example of this is the Taylor Village Fault (Plate 92-34). It shows left-lateral offset of the boundary between the Hillsborough Formation and Windsor Group carbonates. A related oblique en échelon fold occurs west of Peck Creek on the north side of the Taylor Village Fault.

North-south-oriented, gentle closure, macroscopic folds affect the Boss Point Formation and older Carboniferous rocks in the southeastern Moncton Subbasin (Plate 92-34). The most obvious folds of this type are the two south-plunging synclines southwest of Hillsborough and east of Boudreau Village. The spatial association of these folds with the Dorchester and Boudreau fault zones suggests a causative relationship. It is not known whether the folds formed during late dextral or late sinistral movements on the associated northeast-trending faults.

In summary, it is concluded that the Moncton Subbasin probably formed via transtension in Late Devonian/Early Carboniferous time. During its early history the subbasin was filled by mainly coarse-grained Horton deposits resulting from transverse paleocurrent flows along the basin margin and adjacent to contemporaneous intrabasinal uplifts. Horton paleocurrents in the central part of the basin appear to have been largely axially oriented, either northeast or southwest. Present data suggest the existence of two Albert Formation depocentres, one between Berryton and Weldon, the other near Portage Vale.

The Horton strike-slip cycle terminated in a dextral transpressive event evidenced by: (1) a network of northeast-striking anastomosing fault zones, (2) associated right-lateral en échelon folds, (3) strike-slip duplexes, (4) positive flower structures, (5) intrabasinal uplifts, (6) erosion of uplifted Horton sections, and (7) formation of an angular unconformity.

The Horton strike-slip cycle was followed by a period of essentially marine (Windsor Group) and terrestrial (Hopewell Group) sedimentation. Hopewell sedimentation was favoured by synchronous extensional tectonics and resultant normal faulting. Blocks uplifted during this event locally show further erosion of Horton Group and Albert Formation sections. In Late Carboniferous time Horton and younger rocks in the southeastern Moncton Subbasin were transected by northwest-trending reverse faults, and sinistral reactivation occurred on earlier northeast-trending dextral wrench faults. Some of the early dextral faults also show later dextral movements, the latest of which may be Early Jurassic or younger.

The sequence of tectonic events thus described were the major kinematic controls on the present geometry of the Albert Formation and its lithofacies.

ENERGY AND MINERAL RESOURCE IMPLICATIONS

The potential economic implications of this study may be broadly grouped under: (1) energy resources, (2) industrial minerals, and (3) metals. It is not the intent here to give a rigorous treatment of each, only to offer ideas and recommendations for further study.

ENERGY RESOURCES

Oil and natural gas, oil shale, and albertite have been known in the Albert Formation for more than one hundred and fifty years (Dawson, 1853; Wright, 1922; Hume, 1932; Henderson, 1940; King, 1963; Howie, 1965,1968; Macauley, 1981; Foley, 1989).

Oil seeps from Albert Formation sandstones near Stoney Creek, Dover, Boyd Creek, and Saint-Joseph (Plates 92-34 to 92-36) were known to Dr. H. C. Tweedel when he drilled four shallow wells in the area in 1859 (Hume, 1932). From 1901 to 1906, about 70 shallow wells were put down near Dover and Saint-Joseph from which about 3 000 barrels of oil were taken (Howie, 1968; Foley, 1989), but it was in 1909 when the most significant discovery was made at Stoney Creek. It was there that Maritime Oilfields Limited drilled the first well to produce "large quantities" of natural gas and promising quantities of oil (Hume, 1932; Henderson, 1940; Foley, 1989). From 1909 to 1986, 156 wells were drilled in the Stoney Creek sandstone reservoir (Figures 35a and 35b). The field produced 803 800 barrels of oil from the time of discovery to 1988 when production ceased. From 1912 to 1991, the field yielded 803 702 450 m^3 of natural gas; production terminated in March 1991 due to depleted reservoir pressure.

Early development drilling at Stoney Creek proceeded from east to west. The productive field extended along strike from Highway No. 114 to a point about 4 km to the west of there. The width of the producing sands extended in a north-south dip-direction for about 2 km (Hume, 1932). The early step-out wells drilled west of Stoney Creek, for example, Maritime Oilfields Ltd. No. 27, N.B.G.O. No. 100, and N.B.G.O. No. 115 (borehole Nos. 10, 11, and 12 respectively, Plates 92-34 to 92-36), encountered nonproductive mainly red coarse conglomerates, sandstones, and minor mudstones; consequently, drilling to the west was discontinued.

From the late 1940s to the mid-1980s, New Brunswick Gas and Oilfields Limited, the operator of the Stoney Creek Field, had successive farmout agreements with Shell Oil Company, Imperial Oil Limited, Orville Parker, and the partnership of Irving Oil Limited and Chevron Canada Resources Ltd. All these companies drilled wildcat wells in the Moncton Subbasin; Parker and Irving/ Chevron also drilled intended development wells in the Stoney Creek Field. The locations of the Irving/Chevron wells are shown on Plates 92-34 to 92-36.

None of the wildcat wells, many of which are shown on Plates 92-34 to 92-36, became oil

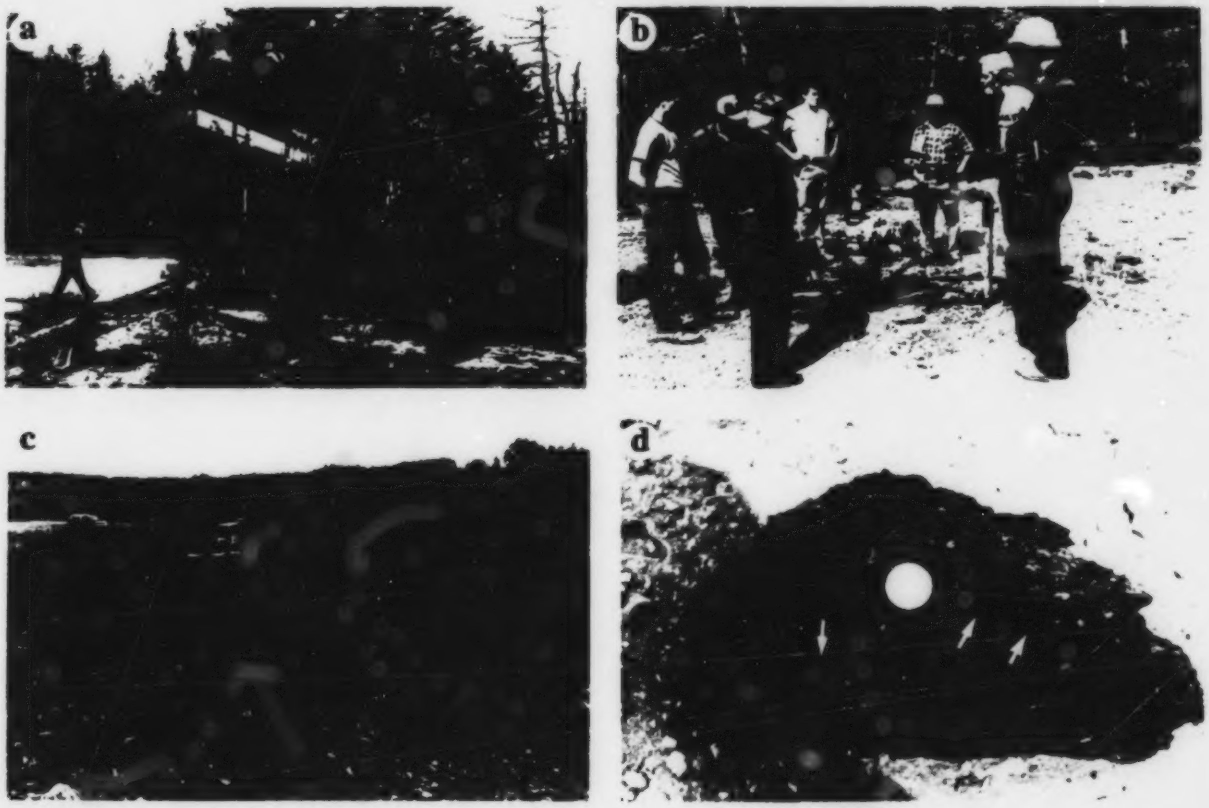

Figure 35: Economic Resources of the Albert Formation. (a) Oil well P8 at the Stoney Creek Gas and Oil Field, 1983; (b) Gas well at the Stoney Creek Gas and Oil Field, 1983; (c) A test pit in oil shales at Frederick Brook was opened by Canadian Occidental Petroleum Ltd. in 1986 to procure a bulk sample for the New Brunswick Electric Power Commission fluidized bed combustor demonstration plant at Chatham, New Brunswick; (d) Oil shale breccia with a matrix of black vitreous albertite (arrows). Sample from tailings pile of old albertite mine at Frederick Brook. Coin is 19 mm in diameter.

or natural gas producers. However, it is reported that the Irving/Chevron Hillsborough No. 1 well could produce gas; the well is presently shut-in.

Why have the wildcat wells been largely unsuccessful? Some possible reasons are offered below in the context of the present study of lithofacies, seismic facies and structural setting of the Albert Formation. This is accompanied by recommendations for future exploration. To begin with, it is a virtual certainty that none of the explorationists had a sufficiently detailed understanding of lithofacies diversity, lithofacies distribution, and structural geometry to judiciously locate drillable prospects in the Albert Formation. Regardless, the fact that holes were drilled has subsequently helped overcome these problems to a degree. The second major problem for all companies prior to Irving/Chevron's entry in the 1980s was the lack of multifold seismic reflection data. Several hundred kilometres of Chevron Canada Resources Ltd. seismic profiles have greatly assisted in interpreting possible subsurface lithofacies and structural configurations. The reader is referred to Plate 92-36 for an interpretation of subsurface lithofacies in the Albert, Plates 92-38 to 92-47 for interpreted seismic profiles, and to Plate 92-48 for a structural panel diagram of the southeastern Moncton Subbasin.

The oil- and gas-producing reservoir sandstones at the Stoney Creek Field and the same sandstones at the old oil field between Dover and Saint-Joseph occur within Albert Formation sandstone facies (As) and mudstone/sandstone facies (Ax) (see Plate 92-36 and pages 39-52). West of Stoney Creek, both lacustrine sandstone facies (As) and mudstone/ sandstone facies (Ax) intertongue with delta or fan-delta conglomerate facies (Ac) (see CONGLOMERATE FACIES, pages 24-39, and seismic evidence of the conglomerate facies on pages 84-85 and Plate 92-42). As noted above, the presence of unproductive conglomerates in Maritime Oilfields No. 27, N.B.G.O. No. 100, and N.B.G.O. No. 115 wells (borehole Nos. 10, 11 and 12 respectively, Plate 92-36) deterred exploration west of Stoney Creek. However, the lithofacies and seismic facies interpretations provided herein and summarized on Plate 92-36 suggest that sandstone facies (As) and mudstone/sandstone facies (Ax) occur west of conglomerate facies (Ac) in the area between Turtle Creek, Parkindale, and Berryton. The sandstones in this area have never been tested by the drill. It is believed that this area has sufficient potential to warrant serious further evaluation. In this regard, it should be noted that Imperial Berryton No. 1 well (borehole No. 5, Plates 92-35 and 92-36) was drilled near the axis of the Weldon Syncline and consequently did not properly evaluate up-dip pinch-outs in potentially producing sands. Also, Irving/Chevron Little River No. 1 well (borehole No. 4, Plates 92-35 and 92-36) was drilled too far down section, that is, too far north, and as a result only encountered lower mudstone facies (Am) of the Albert Formation (see Plate 92-43 and borehole log on Plate 92-36). The fact that the area between Turtle Creek and Parkindale is on the same trend as Stoney Creek and Dover is particularly encouraging. Also, the apparent lack of structural complications may enhance the potential of preserved reservoir seal in this area.

The Irving/Chevron Middlesex No. 1 well (borehole No. 3, Plates 92-34 and 92-35) encountered Green Head Group basement rocks after penetrating Windsor Group and younger strata. This suggests company geologists and geophysicists were unsure of the subsurface distribution of the Westmorland Uplift and consequently of where the Albert section was in this area. The interpreted Horton Group/basement contact on Plate 92-35 together with the Albert Formation facies on Plate 92-36 suggest that the southwestern flank of the Westmorland Uplift from Parkindale to Petitcodiac may hold potential for oil and natural gas. Again by extension, this area has a similar structural setting to that at the Stoney Creek Field.

The potential fault- and/or fold-related traps in the Albert Formation sandstones along the southern margin of the Moncton Subbasin are too abundant to list here. An inspection of maps (Plates 92-35 and 92-36) and seismic profiles (Plates 92-40, 92-41, 92-43, 92-44, 92-46, and 92-47) indicates the possibilities. It should be noted that prolific reserves of hydrocarbons are trapped in en échelon anticlinal folds and faulted folds in the Los Angeles and San Joaquin basins, California (Wilcox, *et al.*, 1973). To date, in the Moncton Subbasin, the only en échelon fold to be drilled is that at Irving/Chevron Hillsborough No. 1 well (borehole No. 19, Plates 92-34 to 92-36). The structure there (Plate 92-41) contains gas and it is presently shut-in. Bitumen is seen in several surface shows along the southern margin of the subbasin (Figure 10d, page 34).

As noted on pages 40 and 64, sandstone facies (As) stratigraphically overlies kerogenous mudstone facies (Ak) in most of the southeastern Moncton Subbasin (Plate 92-36 and Figure 31). The position of oil shale source rocks below prospective sandstone reservoir beds enhances the oil and natural gas potential in the entire southeastern subbasin area.

Oil shales in the Albert Formation were known to prospectors and local people prior to the discovery in 1849 of a black vein of bitumen (albertite) cutting the oil shales at Frederick Brook (Figures 35c and 35d) (Macauley, 1981; Pickerill, *et al.*, 1985; St. Peter, 1988). The reader is referred to KEROGENOUS MUDSTONE FACIES (AK), pages 65, 68 and 70, for a summary account of the economic potential of Albert versus other Canadian oil shales.

Over the past 100 years there has been some controversy regarding the surface and subsurface distribution and the possible quantities of oil shale in the Albert Formation (Ells, 1903, 1908, 1909; Wright, 1922; Alcock, 1948; Ells, 1948; Timm, 1948; Macauley and Ball, 1982; and St. Peter, 1988). The present study provides an interpretation of the distribution of kerogenous mudstone facies (Ak) (Plate 92-36). This map is the most recent synthesis of where high-grade oil shales are likely to occur in the southeastern Moncton Subbasin. As cited above, the organic matter-rich oil shales mostly occur stratigraphically below competent sandstone beds of sandstone facies (As). This may prove beneficial; the sandstones could support or stabilize the roof of any future underground oil shale mine. However, the same sandstones may deter or greatly escalate the cost of surface oil shale mining.

INDUSTRIAL MINERALS

Rock salt and glauberite are the major minerals in Albert evaporite facies (Ae) in the Weldon area (Hamilton, 1961; Webb, 1977; Greiner, 1962; see also EVAPORITE FACIES, pages 56-63). Present drill hole information suggests that the evaporites are centred around Weldon (Plate 92-36; see also Hamilton, 1961; Webb, 1977).

The Albert evaporites are interpreted to give rise to a distinctive seismic reflection facies (AD) (see page 85). The facies is virtually reflection free on seismic line L65YA (Plate 92-40). A wide and thick (500 ms) seismic facies with this characteristic occurs between the Hillsborough and Boudreau faults (Plate 92-40). The facies could imply the existence of significant evaporites in this presently untested area.

Marine evaporites, including extensive potassium chloride salts, occur in the upper part of the Windsor Group in the Sussex area. There are two operating mines in these potash salts, one north of Hillsdale and the other northeast of Sussex (Plate 92-33). Why are the Windsor evaporites restricted to the southwestern Moncton Subbasin? Apparently this part of the basin was temporarily and repeatedly cutoff from the sea, and during such times evaporation, saturation and precipitation of higher-order evaporites took place. For this to have occurred, a sill or a rising obstruction must have prevented open access to the sea. It is generally conceded that the Windsor sea transgressed the Moncton Subbasin from the northeast (Schenk, 1969; McCutcheon, 1981a; Howie, 1988). If this were the case, then the obstruction cutting off the southwestern part of the Moncton Subbasin must have been northeast of the present evaporite deposits.

It is here proposed that the uplifted area around Parkindale, shown on Plate 92-35 where the Horton Group "necks in" from the north and south, was the most likely barrier to the Windsor sea. In addition to its obvious restrictive geometry between uplifted basement rocks on the south and north, further evidence of this being a barrier includes: (1) the absence of Hillsborough or Windsor marine rocks at the surface along the Caledonia Uplift (Plate 92-34), (2) only a very thin basal(?) Windsor section to the north of Caledonia Uplift in the subsurface (Plates 92-44 and 92-45), and (3) a rapidly thickening Windsor section northwest of there, for example, see interpreted seismic line L29Y (Plate 92-47). It can be concluded from the above that the physiography that resulted from the transpression in Horton time imposed a controlling influence on late Windsor deposition. It is also implied that tectonic activity continued during Windsor time, or alternatively that cyclic rising and falling of sea level accounted for periodic over-spilling of the Parkindale barrier.

Barite occurs along the Edgetts Landing Fault at Upper Dorchester and along the Memramcook East Fault 2.5 km north of Memramcook East (Plate 92-34). The two occurrences are the most thoroughly assessed barite showings in New Brunswick (Hamilton, 1968). In both places barite occurs in veins and as breccia fillings. The host rock at Memramcook East is red siltstone of the Memramcook Formation, while at Upper Dorchester it is vuggy siliciclastic and algal limestone of the Gays River Formation. It would appear from this that the primary control on barite mineralization is structural (fault zones) and that the host rock is secondary.

The locations and relative ages of faults in the southeastern Moncton Subbasin are shown on Plates 92-34, 92-35, and 92-36 and described above under EVOLUTION OF MONCTON SUBBASIN DURING THE HORTON STRIKE-SLIP CYCLE AND SUMMARY OF SUBSEQUENT STRUCTURAL EVENTS (page 86). Since barite occurs along the Edgetts Landing and Memramcook East faults, the extensions of these faults should be prospective zones for mineralization. Numerous other northeast-trending faults in the area should also hold potential for barite and associated mineralization (Hamilton, 1968; McLeod and Ruitenberg, 1978).

METALS

Copper was discovered in about 1872 in basal quartzose conglomerates and sandstones of the Boss Point Formation 1 km southeast of Woodhurst (Plate 92-34). The discovery lead to the opening of the Dorchester Copper Mine, which operated intermittently until 1917 (Wright, 1950; McLeod and Ruitenberg, 1978; Rose and Johnson, 1990). Copper minerals include chalcocite and minor chalcopyrite, which occur mainly as fine-grained disseminations and lesser stringer veins associated with carbonaceous plant fragments (McLeod and Ruitenberg, 1978). The deposit is generally thought to be syngenetic (see published and unpublished files in Rose and Johnson, 1990). However, the fact that the Dorchester Fault cuts the Boss Point Formation at the site of the old mine — see anomalous vertically dipping beds on map W-22 of McLeod and Ruitenberg (1978) — suggests a structural control on copper mineralization. Perhaps ore-bearing fluids moved up along the Dorchester Fault zone rather than only laterally along porous beds at the base of the Boss Point Formation. This interpretation is supported by the presence of minor copper mineralization in other rock-types and settings along the Dorchester Fault to the southwest (McLeod, 1980).

The Lumsden copper, lead, zinc, and silver deposit occurs 20 km southwest of the Petitcodiac River on the north side of the Dorchester Fault (Plate 92-33); 15 km southwest of there, in the same zone is the abandoned Teahan copper, lead, and zinc mine. Although both the Lumsden and Teahan occurrences are interpreted as stratiform deposits (Ruitenberg, *et al.*, 1979), their close spatial association with the Dorchester Fault suggests a possible genetic relationship.

A small copper deposit was discovered 2 km south of Goshen in 1925 (Plate 92-34). Secondary malachite and minor primary chalcocite occur there as disseminations and fracture fillings in a bed of green polymictic fanglomerate of the Weldon Formation (see unpublished report by J. Wightman in Rose and

Johnson, 1990). Wilson (1927) interpreted the Goshen copper deposit as probably resulting from the precipitation of chalcocite from copper-rich meteoric waters.

Several companies and geologists have examined the Goshen deposit (Rose and Johnson, 1990). None have suggested that faulting may have been involved in the origin of the deposit. The Gordon Falls Fault occurs immediately south of the deposit (Plate 92-34). Subsidiary faults and shears have been reported in test pits and drill core in the deposit. From this evidence it is suggested that faults may have acted as conduits for the copper-bearing meteoric waters that gave rise to the Goshen occurrence.

In summary, the cupriferous deposits in the Carboniferous strata of the southeastern Moncton Subbasin are spatially and, therefore, possibly genetically related to faults. If this interpretation is correct, then the faults shown on Plates 92-33 to 92-36 should serve as a guide to future exploration.

SUMMARY AND CONCLUSIONS

GENERAL STATEMENT

This section gives a summary of the regional geologic setting of the Moncton Subbasin within the Maritimes Basin, and lists the significant findings and conclusions resulting from the lithofacies and seismic facies analyses of the Albert Formation.

REGIONAL GEOLOGIC SETTING

The Maritimes Basin is a Late Devonian to Permian successor basin, the erosional remains of which have a surface area of about 150 000 km^2 (Figure 1, page 3). The basin fill is up to 8 km thick in its axial part and lies with angular unconformity on Middle Devonian and older rocks. The fill comprises mainly terrestrial clastics with minor volcanics, terrestrial and marine evaporites, and marine carbonates. The Middle Devonian and older rocks of the northeastern Appalachians that underlie the Maritimes Basin have been divided into five northeast-trending tectonostratigraphic zones or terranes (Williams, 1979; Williams and Hatcher, 1982). From north to south the terrane names are: Humber, Dunnage, Gander, Avalon, and Meguma (Figure 2, page 4). The fault boundaries of the terranes, and numerous faults within them, show evidence of several periods of late Paleozoic movement. Displacements on the faults are believed to be responsible for the inception of the Maritimes Basin and for the subsequent deformation of its fill.

The initial subsidence of the Maritimes Basin took place within a series of Late Devonian to Early Carboniferous relatively small northeast- to east-northeast-trending sedimentary subbasins such as the Moncton Subbasin of southeastern New Brunswick (Figure 3, page 7). The subbasins were separated in part or in whole by arches or uplifts that provided circum-basinal supplies of detritus (Kelley, 1967; Howie and Barss, 1974, 1975).

The first terrestrial fill in the subbasins was the Horton Group. In the Moncton Subbasin it comprises three conformable formations: the basal mainly red Memramcook Formation, the medial mainly grey Albert Formation, and the upper mainly red Weldon Formation. The Horton Group in the Moncton Subbasin is greater than 4 km thick in the most completely preserved (least eroded) parts of the section.

The Horton Group was deformed in the late Tournaisian or early Visean (Gussow, 1953; Smith and Collins, 1984). Following the deformation, and a period of uplift and erosion, the Moncton Subbasin and the Maritimes Basin in general underwent a second phase of subsidence, this time below sea level, as evidenced by the laterally extensive and mostly marine Windsor Group. The Windsor sea retreated in the late Visean and in its wake individual subbasins within the Maritimes Basin again became the sites of extensive proximal alluvial to distal fluvial and lacustrine deposition as recorded by the Namurian Mabou, Canso, and Hopewell groups. In the Moncton Subbasin the Windsor and Hopewell strata were deformed and subsequently unconformably overlain by Westphalian and younger mainly fluviatile beds of the Cumberland and Pictou groups. Thus, in most subbasins in the Maritimes Basin, and certainly in the Moncton Subbasin, the stratigraphic succession comprises three depositional sequences: (1) the Horton Group, (2) the Windsor/Hopewell groups, and (3) the Cumberland/Pictou groups. The three depositional sequences in the Moncton Subbasin are seen from field evidence and seismic reflection profiles to be separated by angular unconformities.

FINDINGS AND CONCLUSIONS

The significant findings resulting from the lithofacies and seismic facies analyses of the Albert Formation undertaken in this study can be grouped under four headings: (1) resolution of stratigraphic problems in the Moncton Subbasin, (2) clarification of stratigraphy, lithofacies architecture, and environments of deposition of the Albert Formation, (3) documentation of features affecting the evolution of the Moncton Subbasin, and (4) elucidation of constraints on energy and mineral resources in the Moncton Subbasin.

Resolution of Stratigraphic Problems

Norman (1941) defined the Moncton Group as the upper redbed unit of the Horton Group. It is recommended that the name 'Moncton Group' be abandoned, but that the formations within the group and their names, i.e., Weldon Formation and Hillsborough Formation be retained (cf., Carter and Pickerill, 1985b). The recognition in outcrop and in seismic profiles of an angular unconformity between the lower Weldon Formation and the overlying Hillsborough Formation throughout the Moncton Subbasin is compelling evidence to redefine the upper Horton Group litho-stratigraphy. Accordingly, it is informally recommended that the Weldon Formation be assigned as the upper formation of the Horton Group and that the Hillsborough Formation be excluded from the Horton Group and instead placed at the base of the overlying Windsor Group with which it is conformable (Gussow, 1953; McCutcheon, 1981a).

The Boyd Creek Tuff does not occur near the base of the Hillsborough Formation as suggested by Gussow (1953) and Shroder (1963). The tuff does not transgress the boundary between the Weldon and Hillsborough formations and, therefore, it does not imply the facies equivalency of the latter formations (McLeod, 1980). The Boyd Creek Tuff is restricted to the folded and deformed Weldon Formation; it does not occur in the relatively undeformed and unconformably overlying Hillsborough Formation.

The name 'Cumberland Group' is informally extended form northern Nova Scotia to southern New Brunswick. It is used in this report to include two conformable formations: (1) a lower redbed unit, the Enragé Formation, that historically has been defined as the uppermost formation of the Hopewell Group (Norman, 1941; Gussow, 1953; Leger, 1969; van de Poll, 1972), and (2) an overlying unit of quartzose conglomerates, quartzose sandstones, and mudstones of the Boss Point Formation that previously was included in the Riversdale Group (Gussow, 1953; van de Poll, 1972, 1978). In this regard, the Cumberland Group is correlated with the recently redefined Cumberland Group of Nova Scotia (Ryan, *et al.*, 1990a, 1990b, 1990c, 1991).

Albert Formation

The Albert Formation is subdivided into six lithofacies. The lithofacies and their interpreted environments of deposition are: (1) basin margin proximal alluvial fan and fan-delta conglomerates, (2) transgressive/regressive shallow lacustrine sandflats, (3) interstratified marginal lacustrine mudstones and sandstones, (4) subaerial mudflats, (5) deep lacustrine organic matter-rich mudstones and oil shales, and (6) perennial and ephemeral (playa) saline lake evaporites.

The principles of seismic facies analysis (Mitchum, *et al.*, 1977a, 1977b; Van Wagoner, *et al.*, 1988) that are usually applied to marine sequences are in this report applied to the terrestrial Albert formation. Four seismic facies are identified and correlated with Albert lithofacies (Table 4, page 86). Extrapolation of the seismic facies into the subsurface and away from boreholes is used to more accurately define the distribution of the six Albert lithofacies. The most significant observations and conclusions arising for the lithofacies and seismic facies study are listed below:

(1) The contact between the Albert and Memramcook formations is redefined. The red and grey mudstones that have traditionally been placed in the upper part of the Memramcook Formation in the southeastern Moncton Subbasin (Carr, 1968; McLeod and Ruitenberg, 1978) are assigned to the Albert Formation, thereby restricting the Memramcook Formation to the coarse clastic strata at the base of the Horton Group.

(2) The conglomerate lithofacies is seen to be mainly confined to four areas that are interpreted as the loci of alluvial fans/fan-deltas. Paleocurrents and detritus composition indicate that three of the fan/fan-delta complexes were derived from the Caledonia Uplift to the south of the Moncton Subbasin. The fourth fan appears to have been derived from the north of the Westmorland Uplift.

(3) The Round Hill Formation (McLeod, 1980), or the Round Hill Member of the Albert Formation (Carter and Pickerill, 1985b) is here interpreted to be a local alluvial fan conglomerate facies restricted to the upper part of the Albert Formation.

(4) The names 'Gautreau Formation' of Norman (1932), and 'Gautreau Member' of Carter and Pickerill (1985b) are dropped. The evaporites that define this unit are seen to be a geographically restricted lithofacies in the upper part of the Albert Formation. A detail log and description is given in Figure 22 (page 58) of an evaporite reference section at Sifto Salt No. W3 well. Prolific desiccation features imply an ephemeral playa lake origin for most of the evaporites.

(5) Sandstones, grainstones and wackestones within both the sandstone facies and mudstone/sandstone facies are interpreted as the products of marginal lacustrine processes, including distal alluvial plain sheetfloods and variably directed within-lake storm currents. The siliciclastic sandstones contain significantly more quartz than the sandstones associated with the conglomerate facies, possibly attesting to greater reworking in the near-shore environment. In contrast to previous interpretations of fluvial and fluvial/deltaic deposition, fining-upward

and coarsening-upward cycles are interpreted as transgressive and regressive cycles, respectively. They are believed to result from a periodically expanding and retreating lake strand line.

(6) Kerogenous mudstone facies occurs in the medial part of the Albert Formation. Synsedimentary slump folds and oil shale breccias within the kerogenous mudstone facies imply penecontemporaneous seismic activity and also that paleolake Albert was possibly characterized by significant bathymetric relief. The unbioturbated organic matter-rich oil shales, which bear articulated fish fossils, suggest a meromictic water body with a permanently anoxic profundal zone.

(7) Lithofacies distributions, regional paleocurrent trends, and formation thickness variations indicate there were two loci of Albert deposition in the southeastern Moncton Subbasin: one in the Berryton/Weldon area, and the other in the Portage Vale area (Plates 92-33 and 92-35).

Evolution of Moncton Subbasin

A synthesis of structural evidence suggests that a broad dextral wrench fault zone developed in the northern Appalachians in late Paleozoic time in conjunction with accretion of the Avalon and Meguma terranes (Bradley, 1982; Ferrill and Thomas, 1988). The Moncton Subbasin was initiated in this wrench zone by displacements on interterrane and intraterrane faults immediately south of the Gander/Avalon suture in Late Devonian time (cf., Figures 1 and 2). The Moncton Subbasin may have opened obliquely to its present structural and erosional boundaries. This is implied by north-northeast-trending sandstone dykes in the Albert Formation at Upper Dorchester.

Subsidence in the Moncton Subbasin throughout the Horton depositional cycle was mainly controlled by basin-margin faults. Predominantly coarse alluvial facies accumulated along the basin margins; the distal axial part of the subbasin was dominated by finer grained fluvial and lacustrine facies. The Horton depocentres accumulated greater than 4 km of section prior to erosion.

The Horton depositional cycle ended as the result of a dextral transpressive event that inverted the section. Evidence of this includes: (1) an anastomosing network of northeast- to east-northeast-trending wrench and reverse dip-slip faults along both the southern and northern subbasin margins, (2) formation of right-handed en échelon folds in Horton rocks adjacent to many of the northeast-trending faults, (3) formation of positive flower structures that are interpretable from field evidence and supported by seismic profiles, (4) formation of a compressional strike-slip duplex in the Elgin area, (5) development of intrabasinal uplifts, (6) erosion of part, or in places all, of the Horton section over the intrabasinal uplifts, (7) creation of an angular unconformity at the base of the Windsor Group (Hillsborough Formation) that can be seen everywhere in the subbasin on seismic profiles. The net result of the transpressive event was the formation of structural subbasins, now evident as the erosional remnants of isolated or semi-isolated Horton-filled depressions.

The Horton depositional/tectonic cycle was followed by a second period of subsidence in the Moncton Subbasin with resultant deposition of the Windsor and Hopewell groups. Windsor deposition began with a coarse-grained terrestrial unit, the Hillsborough Formation. Continued subsidence led to transgression of the subbasin by the Windsor sea and deposition of the only marine rocks in the subbasin. Retreat of the Windsor sea occurred in concert with renewed uplift of extra-basinal and intra-basinal source areas. Evidence of the uplift is shown by coarse-grained alluvial strata in the upper part of the Windsor Group in the Hopewell Cape area (Plate 92-33) on the southeastern side of the Caledonia Uplift (McCutcheon, 1981a). Hopewell Group lithofacies in the Moncton Subbasin show coarse proximal alluvial fan facies adjacent to the Caledonia Uplift that grade northward into red mudstones and fine-grained sandstones in the distal axial part of the subbasin.

The Windsor/Hopewell depositional cycle ended in late Namurian time as the consequence of a major compressional (transpressional?) event. This second period of deformation affecting the Carboniferous succession is marked by reverse dip-slip on several northeast-trending faults cutting the Windsor/Hopewell sequence. The northwest-striking and northeast-dipping Gaytons and La Montagne faults were also active at this time. The uplift and ensuing erosion resulting form the deformation is seen as an angular unconformity at the base the Cumberland Group. In the south-eastern part of the subbasin the Hopewell Group is entirely eroded and basal Cumberland rocks of the Enragé Formation lie on lower Windsor Group and older beds.

The Windsor/Hopewell depositional/tectonic cycle was succeeded by a third period of subsidence in the Moncton Subbasin. Record of that subsidence is shown by deposition of the Cumberland and Pictou groups, which are composed of mainly high sinuosity fluvial deposits. The Cumberland and Pictou groups are not confined to the Moncton Subbasin; they form a regionally distributed sequence, and accordingly, reflect a major phase of subsidence and deposition that affected the entire Maritimes Basin.

The Cumberland and Pictou groups are cut locally by northeast-trending faults that are predominantly reactivated Carboniferous and older structures. The Pictou Group is most intensely deformed along the northwestern side of the Moncton Subbasin; for example, Pictou sandstones are seen to dip vertically in the Berry Mills Fault zone in the McQuade Brook area (Plate 92-33).

The dextral transpression affecting the Late Devonian/Carboniferous section in the Moncton Subbasin is interpreted to be the result of dextral collision (Eisbacher, 1969; Keppie, 1982) of the outboard Meguma terrane with the Avalon terrane as evidenced by the Variscan thrust front along the north shore of the Bay of Fundy (Rast, 1984; Mosher and Rast, 1984; Nance, 1986b; Nance and Warner, 1986; Rast and Skehan, 1991). If so, the presence of three unconformities in the section (i.e., at the base of the Windsor Group, at the base of the Cumberland Group, and at the base of the Triassic/Jurassic Fundy Group) suggests the Meguma terrane accreted to the Avalon terrane not in a one-time collision, but as the result of a prolonged convergence during which there were three significant compressions or transpressions.

Energy and Mineral Resources

The lithofacies and seismic facies subdivisions of the Albert Formation indicate there is an interstratified sandstone/mudstone lithofacies west of the Stoney Creek Gas and Oil Field in the Turtle Creek area (Plate 92-36). The prospect has yet to be tested for hydrocarbons. The Albert beds in the Turtle Creek area dip to the south and lie unconformably below the Hillsborough Formation. The beds display an analogous setting to the reservoir sands at Stoney Creek. En échelon anticlines associated with faults along the southern margin of the Moncton Subbasin also hold promise for oil and/or natural gas in the Albert Formation.

Copper and barite occurrences in the Moncton Subbasin are known to be at least in part controlled by fluid migration within fault zones. The discovery of previously unknown faults and the synthesis of fault chronology given in this report should assist in the exploration for copper, barite, and other potential epigenetic mineral deposits.

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APPENDIX 1

NOTES

1. The following four-page table gives all the photographic figure numbers listed in this report. Also, the number and geographic location of each outcrop or outcrop sample from which the photographs were taken are given in the table.

2. The geographic location for each photographed outcrop is shown by a dot (●) on the accompanying seven maps which are keyed to the table. The other outcrops shown on the maps are exposures visited during mapping of the Albert Formation, but which were not specifically utilized in preparation of the report.

3. All rock samples, core samples, well cuttings and thin sections examined in the preparation of the report are stored in the Department of Natural Resources and Energy repository in Fredericton, New Brunswick.

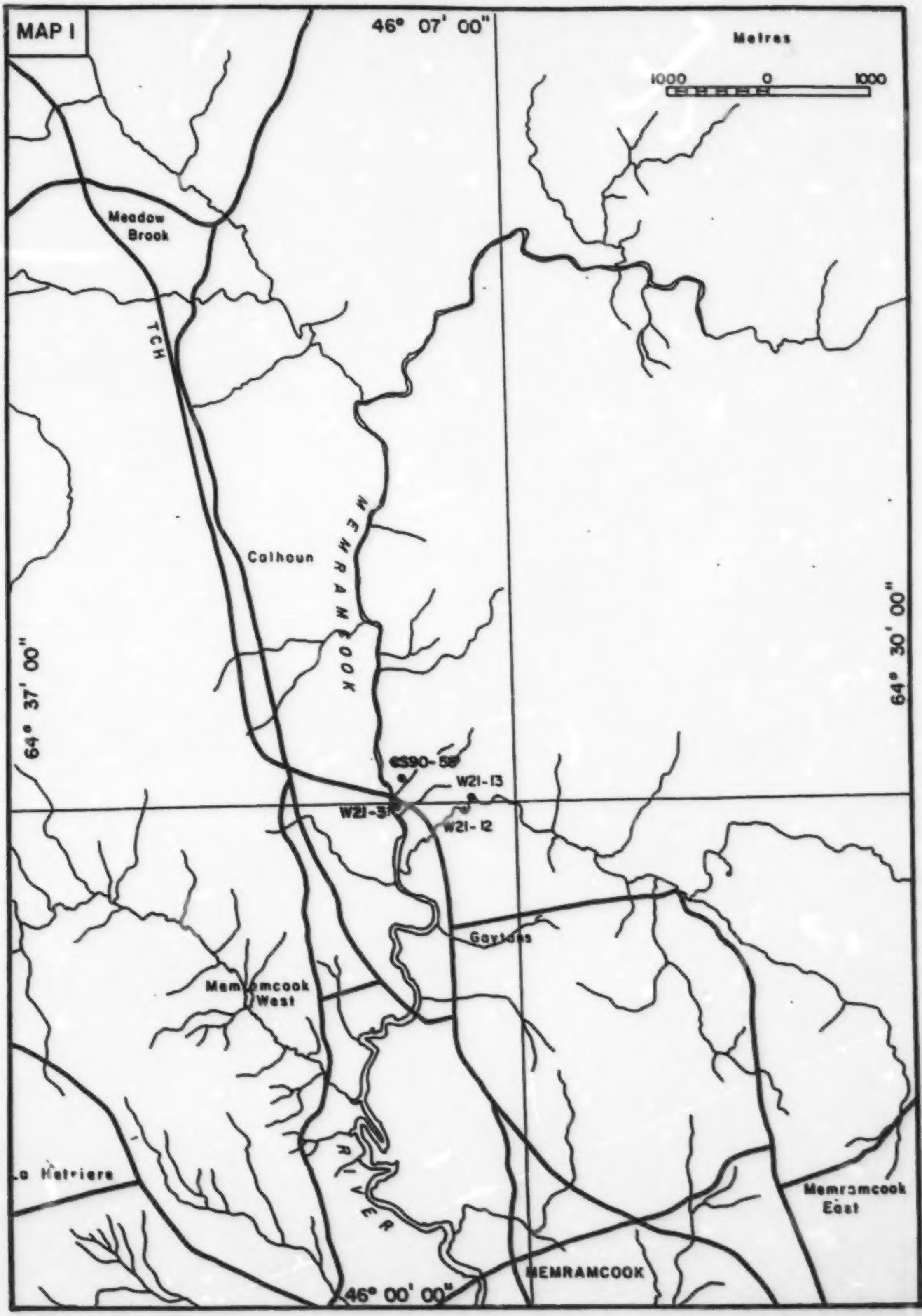
LOCATION OF OUTCROPS AND BOREHOLES FOR PHOTOGRAPHIC FIGURES IN GEOSCIENCE REPORT 92-2

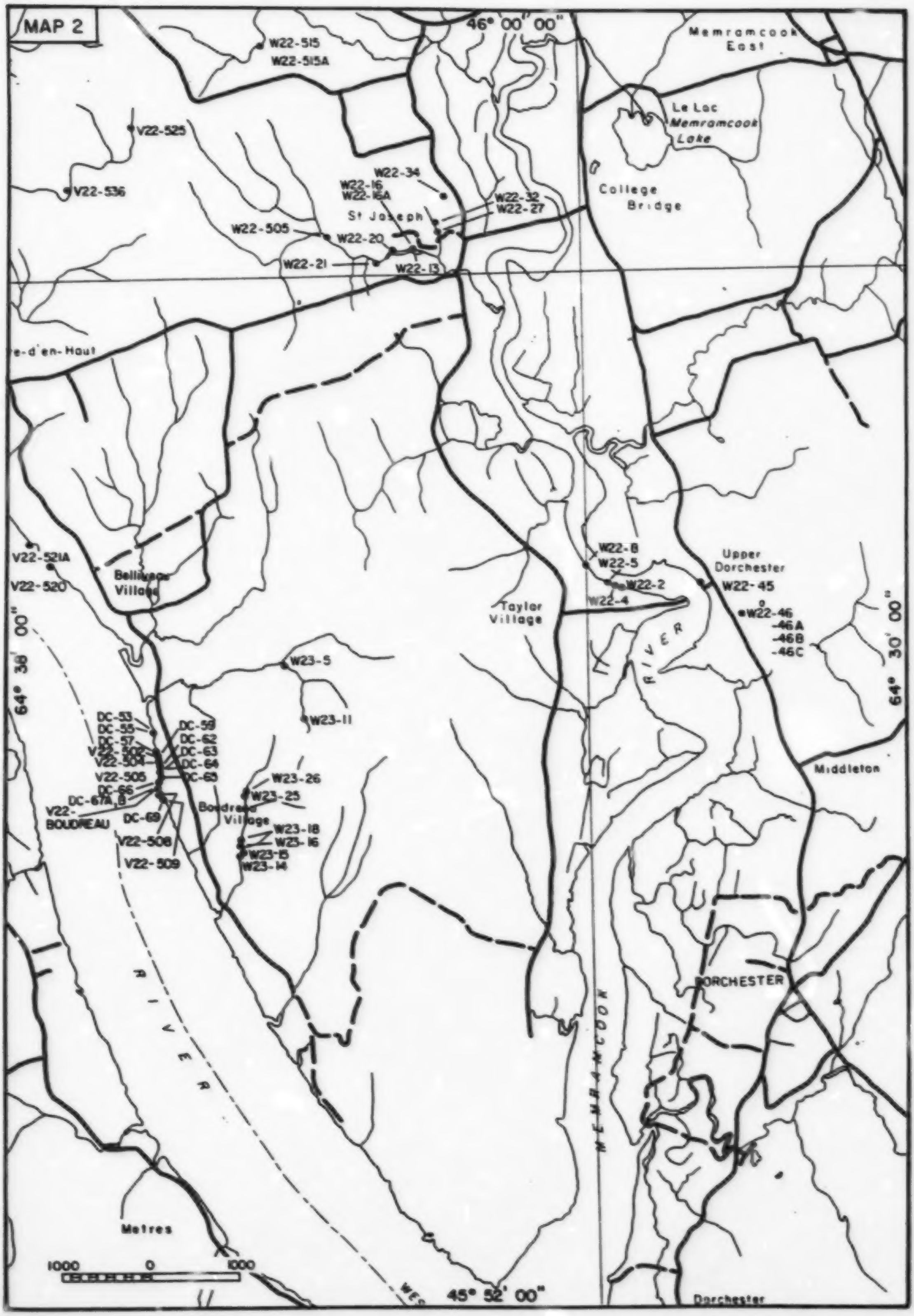
Figure No.	Outcrop No.	Map	Latitude°	Longitude°	Location
4a	T24-16	6	45.7889	65.0983	Pollett River
4b	W21-3	1	46.0445	64.5661	100 m south of Gaytons quarry
4c	CS90-58	1	46.0472	64.5655	Gaytons quarry
4d	CS90-58	1	46.0472	64.5655	Gaytons quarry
6a	T24-11	6	45.7923	65.1006	Pollett River
6b	T24-6	6	45.7945	65.1039	Pollett River
6c	U23-15a	4	45.8463	64.8763	On east side of road at Stuart Brook
6d	T23-27	6	45.8004	65.1026	Pollett River
7a	T23-27	6	45.8004	65.1026	Pollett River
7b	T23-27	6	45.8004	65.1026	Pollett River
7c	V22-505	2	45.9212	64.6109	Boudreau Village section on east side of Petitcodiac River
7d	T24-2	6	45.7969	65.1035	Pollett River
8a	CS90-19	3	45.8838	64.7148	Peck Creek
8b	R25-25	7	45.6507	65.4353	7.5 km southeast of Sussex Corner
8c	U23-2	4	45.8423	64.8763	Stuart Brook
8d	T23-617	6	45.8308	65.0580	Popple Intervale Brook
9a	T24-6	6	45.7945	65.1039	Pollett River
9b	T23-27	6	45.8004	65.1026	Pollett River
9c	U23-4	4	45.8415	64.8761	Stuart Brook
9d	T24-9	6	45.7935	65.1016	Pollett River
10a	CS90-27	6	45.8309	65.0584	Popple Intervale Brook
10b	T24-9	6	45.7935	65.1016	Pollett River
10c	V23-61	3	45.8730	64.7062	Frederick Brook Area
10d	V23-61	3	45.8730	64.7062	Frederick Brook Area
11a	V22-508	2	45.9191	64.6106	Boudreau Village Section
11b	T24-9	6	45.7935	65.1016	Pollett River
11c	U23-113	5	45.8422	64.9673	2 km southeast of Parkindale

Figure No.	Outcrop No.	Map	Latitude°	Longitude°	Location
11d	U23-113	5	45.8422	64.9673	2 km southeast of Parkindale
12a	U23-113	5	45.8422	64.9673	2 km southeast of Parkindale
12b	U23-113	5	45.8422	64.9673	2 km southeast of Parkindale
12c	U23-636	5	45.8249	64.9969	Little River, 2.75 km south of Parkindale
14a	V22-61	3	45.9776	64.6892	Stoney Creek Gas and Oil field
14b	V22-502	2	45.9232	64.6113	Boudreau Village Section
14c	V22-509	2	45.9185	64.6103	Boudreau Village Section
14d	V22-509	2	45.9185	64.6103	Boudreau Village Section
15a	V22-509	2	45.9185	64.6103	Boudreau Village Section
15b	CS90-12	6	45.8152	65.0726	Mapleton Brook
15c	V22-509	2	45.9185	64.6103	Boudreau Village Section
15d	V22-509	2	45.9185	64.6103	Boudreau Village Section
16a	CS90-26	6	45.8305	65.0579	Popple Intervale Brook
16b	CS90-22	6	45.8268	65.0552	Popple Intervale Brook
16c	T23-557	6	45.8161	65.0731	Mapleton Brook
16d	T23-557	6	45.8161	65.0731	Mapleton Brook
16e	T23-557	6	45.8161	65.0731	Mapleton Brook
17a	V23-26	3	45.8756	64.6952	Frederick Brook
17b	V23-26	3	45.8756	64.6952	Frederick Brook
17c	V23-26	3	45.8756	64.6952	Frederick Brook
17d	V23-26	3	45.8756	64.6952	Frederick Brook
18a	V23-26	3	45.8756	64.6952	Frederick Brook
18b	V22-509	2	45.9185	64.6103	Boudreau Village Section
18c	V22-509	2	45.9185	64.6103	Boudreau Village Section
18d	V22-509	2	45.9185	64.6103	Boudreau Village Section
19a	V22-502	2	45.9232	64.6113	Boudreau Village Section
19b	V22-502	2	45.9232	64.6113	Boudreau Village Section
19c	V22-502	2	45.9232	64.6113	Boudreau Village Section
20a	V22-502	2	45.9232	64.6113	Boudreau Village Section
20b	V22-502	2	45.9232	64.6113	Boudreau Village Section

Figure No.	Outcrop No.	Map	Latitude°	Longitude°	Location
20c	V22-502	2	45.9232	64.6113	Boudreau Village Section
20d	Hole RV-3	4	45.8628	64.8144	Borehole, DNRE Rosevale No. 3, depth of 106.65 m
21a	Sifto W3 well	3	45.9530	64.6748	Depth of 200.9 m, Weldon
21b	Sifto W3 well	3	45.9530	64.6748	Depth of 199.4 m, Weldon
21c	Sifto W3 well	3	45.9530	64.6748	Depth of 206.6 m, Weldon
23a	Sifto W3 well	3	45.9530	64.6748	Depth of 362 m
23b	Sifto W3 well	3	45.9530	64.6748	Depth of 314 m
23c	Sifto W3 well	3	45.9530	64.6748	Depth of 310 m
23d	Sifto W3 well	3	45.9530	64.6748	Depth of 337 m
23e	Sifto W3 well	3	45.9530	64.6748	Depth of 331 m
24a	Sifto W3 well	3	45.9530	64.6748	Depth of 286.3 m
24b	Sifto W3 well	3	45.9530	64.6748	Depth of 286.3 m
24c	Sifto W3 well	3	45.9530	64.6748	Depth of 293.3 m
24d	Sifto W3 well	3	45.9530	64.6748	Depth of 349.4 m
24e	Sifto W3 well	3	45.9530	64.6748	Depth of 343.0 m
25a	Sifto W3 well	3	45.9530	64.6748	Depth of 265 m
25b	Sifto W3 well	3	45.9530	64.6748	Depth of 350 m
25c	Sifto W3 well	3	45.9530	64.6748	Depth of 293 m
25d	Sifto W3 well	3	45.9530	64.6748	Depth of 267 m
25e	Sifto W3 well	3	45.9530	64.6748	Depth of 298 m
26a	W22-5	2	45.9405	64.5443	West bank of Memramcook River at Taylor Village
26b	V23-16	3	45.8777	64.6949	Frederick Brook
26c	V23-49	3	45.8838	64.6923	Frederick Brook, Can. Oxy Test Pit near V23-49
26d	DC-79A	3	45.9895	64.6526	Downing Creek
28a	V23-15	3	45.8783	64.6946	Frederick Brook
28b	W22-4	2	45.9401	64.5431	West bank of Memramcook River at Taylor Village
28c	V23-49	3	45.8838	64.6923	Frederick Brook, Can. Oxy. test pit near outcrop V23-49

Figure No.	Outcrop No.	Map	Latitude°	Longitude°	Location
28d	V23-15	3	45.8783	64.6946	Frederick Brook
29a	U23-56	4	45.8491	64.8653	Stuart Brook
29b	W22-4	2	45.9401	64.5431	West bank of Memramcook River at Taylor Village
29c	W22-45	2	45.9405	64.5308	East bank of Memramcook River at Upper Dorchestor
29d	W22-4	2	45.9401	64.5431	West bank of Memramcook River at Taylor Village
30a	W23-16	2	45.9136	64.5990	Unnamed brook SE of Boudreau Village
30b	Hole RV-5	4	45.8631	64.8053	Borehole DNRE Rosevale No. 5, depth of 64.6 m
30c	Hole RV-5	4	45.8631	64.8053	Borehole DNRE Rosevale No. 5, depth of 135.7 m
30d	U23-512	4	45.8589	64.8059	Bray Brook near Rosevale
32a	V22-508	2	45.9191	64.6106	Boudreau Village Section
32b	V22-504	2	45.9223	64.6110	Boudreau Village Section
32c	V22-520	2	45.9423	64.6269	Belliveau Village Section
32d	V22-521A	2	45.9445	64.6302	Belliveau Village Section
33a	T24-6	6	45.7945	65.1039	Pollett River
33b	T24-9	6	45.7935	65.1016	Pollett River
33c	CS90-58	1	46.0472	64.5655	Gaytons quarry
33d	CS90-58	1	46.0472	64.5655	Gaytons quarry
34a	CS90-16	3	45.8844	64.7156	Peck Creek
34b	CS90-16	3	45.8844	64.7156	Peck Creek
34c	CS90-16	3	45.8844	64.7156	Peck Creek
34d	V23-60B	3	45.8730	64.7075	Frederick Brook area
35a	Well P8	3	45.9644	64.6950	Stoney Creek Gas and Oil Field
35b	Well ?	3	?	?	Stoney Creek Gas and Oil Field
35c	Test Pit	3	45.8838	64.6900	Canadian Occidental Petroleum Test Pit, Albert Mines
35d	Stockpile	3	45.8792	64.6968	Albertite Mine Stockpile at Albert Mines


MAP I
46° 07' 00"
Metres
1000 0 1000
Meadow Brook
TCH
Calhoun
MEMRAMCOOK
64° 37' 00"
64° 30' 00"
6S90-58
W21-13
W21-31
W21-12
Gaytons
Memramcook West
La Hetriere
RIVER
Memramcook East
MEMRAMCOOK
46° 00' 00"


MAP 2
46° 00' 00"
W22-515
W22-515A
Memramcook
East
Le Lac
Memramcook
Lake
V22-525
V22-536
W22-34
W22-16
W22-16A
W22-32
W22-27
St Joseph
College
Bridge
W22-505
W22-20
W22-21
W22-13
re-d'en-Haut
V22-521A
V22-520
Bellivea
Village
W22-8
W22-5
W22-2
W22-4
Taylor
Village
Upper
Dorchester
W22-45
W22-46
-46A
-46B
-46C
64° 30' 00"
64° 38' 00"
RIVER
W23-5
W23-11
DC-53
DC-55
DC-57
V22-502
V22-504
V22-505
DC-66
DC-67A, B
V22-
BOUDREAU
DC-59
DC-62
DC-63
DC-64
DC-65
DC-69
V22-508
V22-509
W23-26
W23-25
Boudreau
Village
W23-18
W23-16
W23-15
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Middleton
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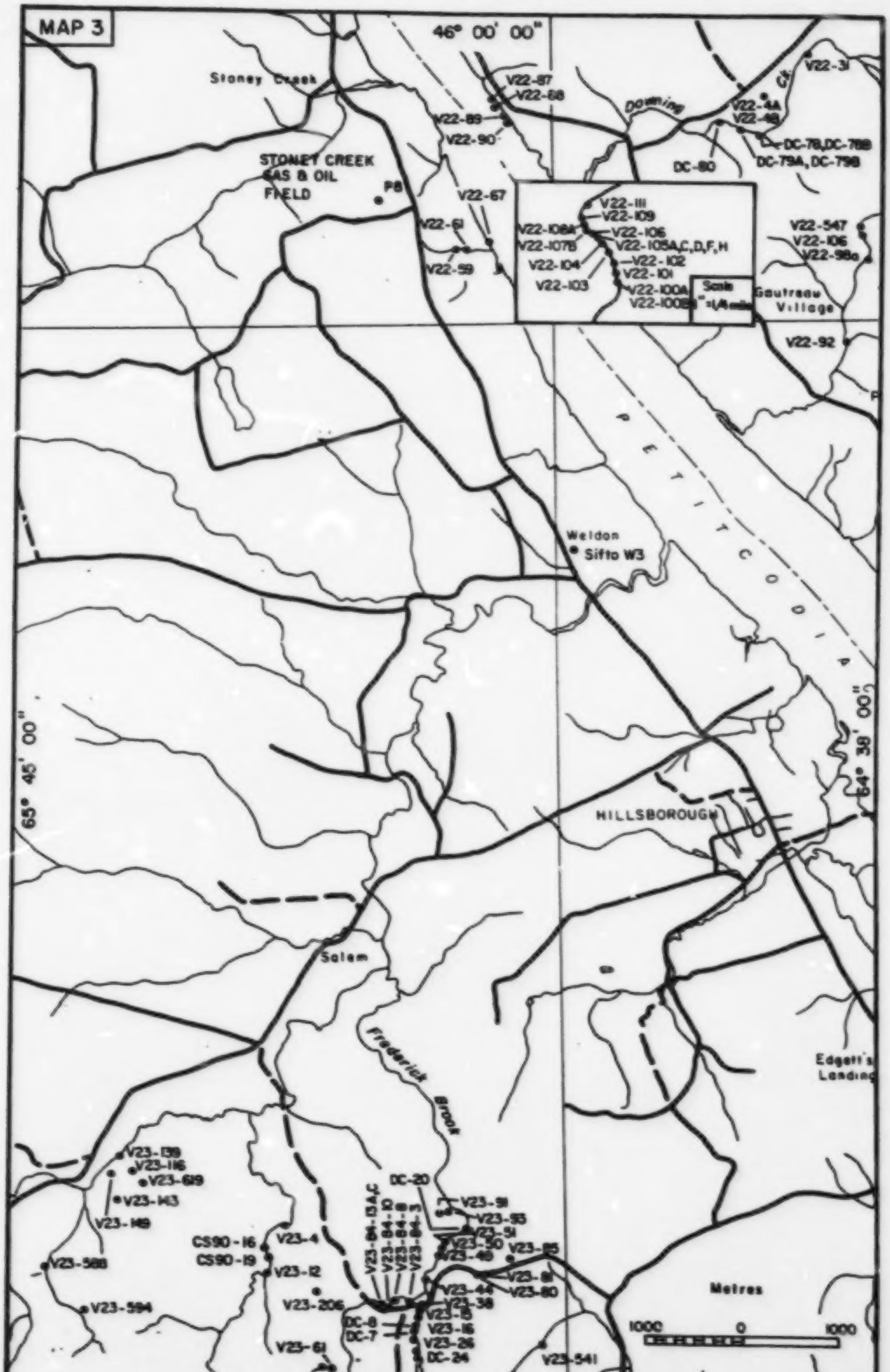
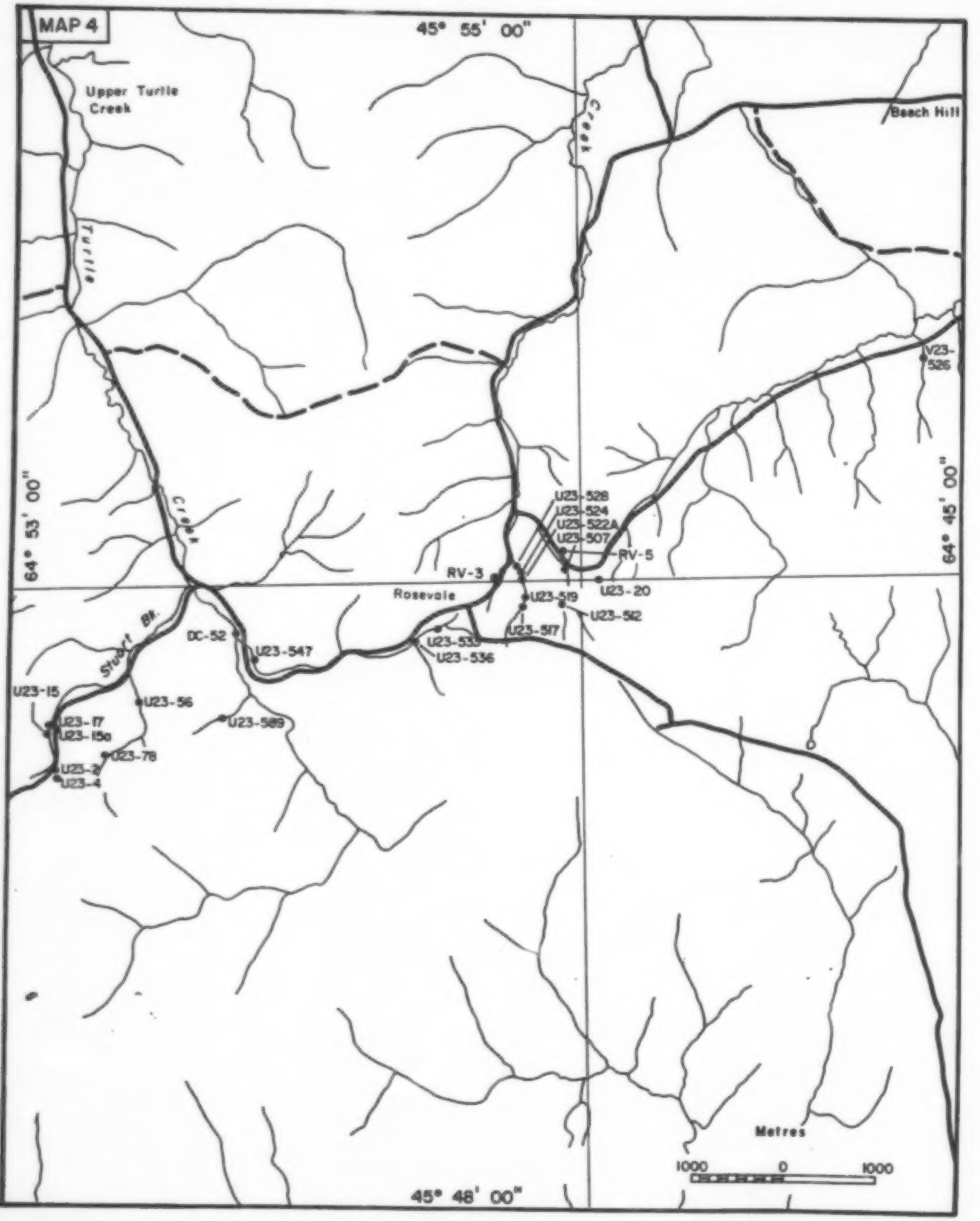
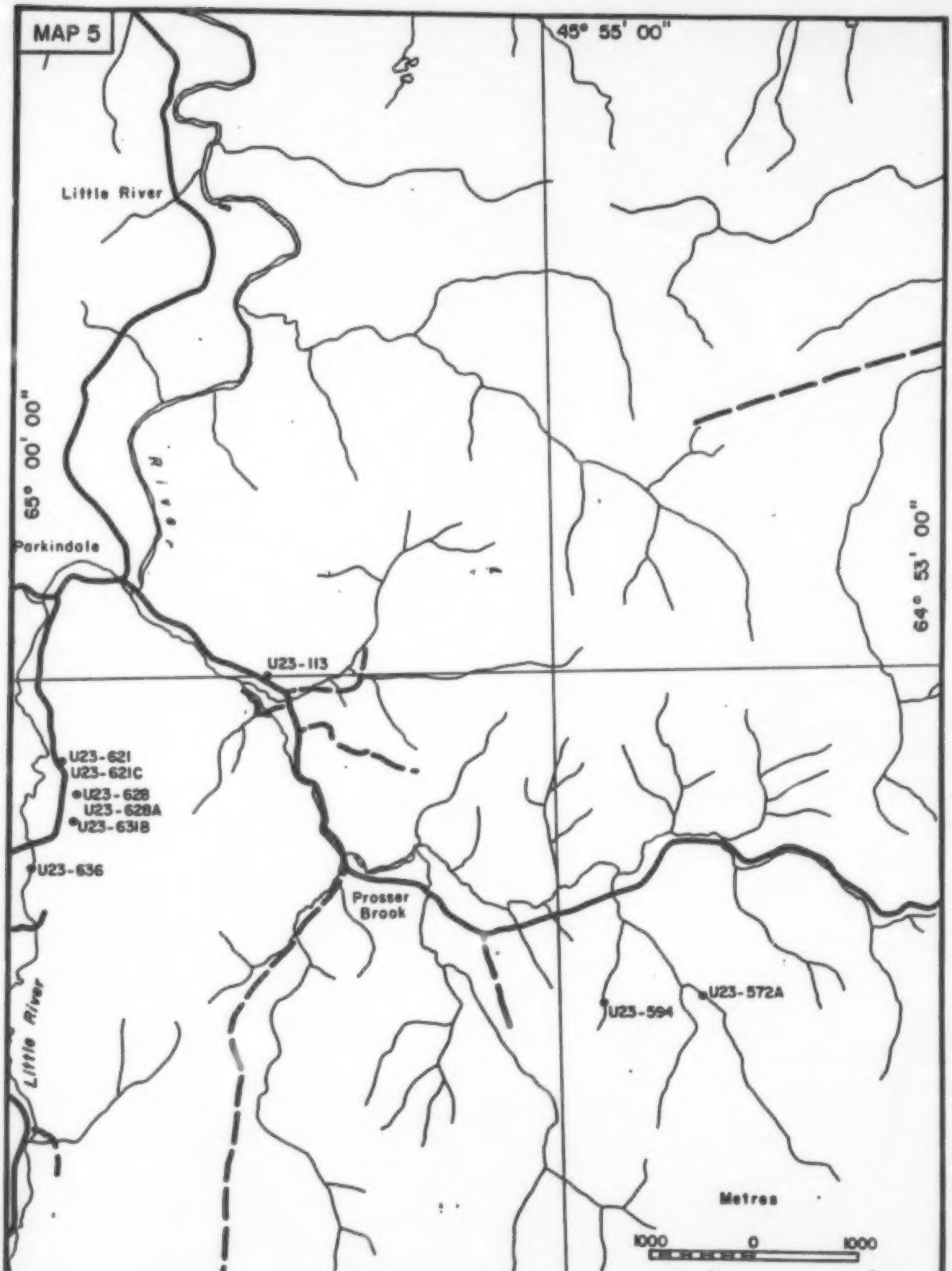
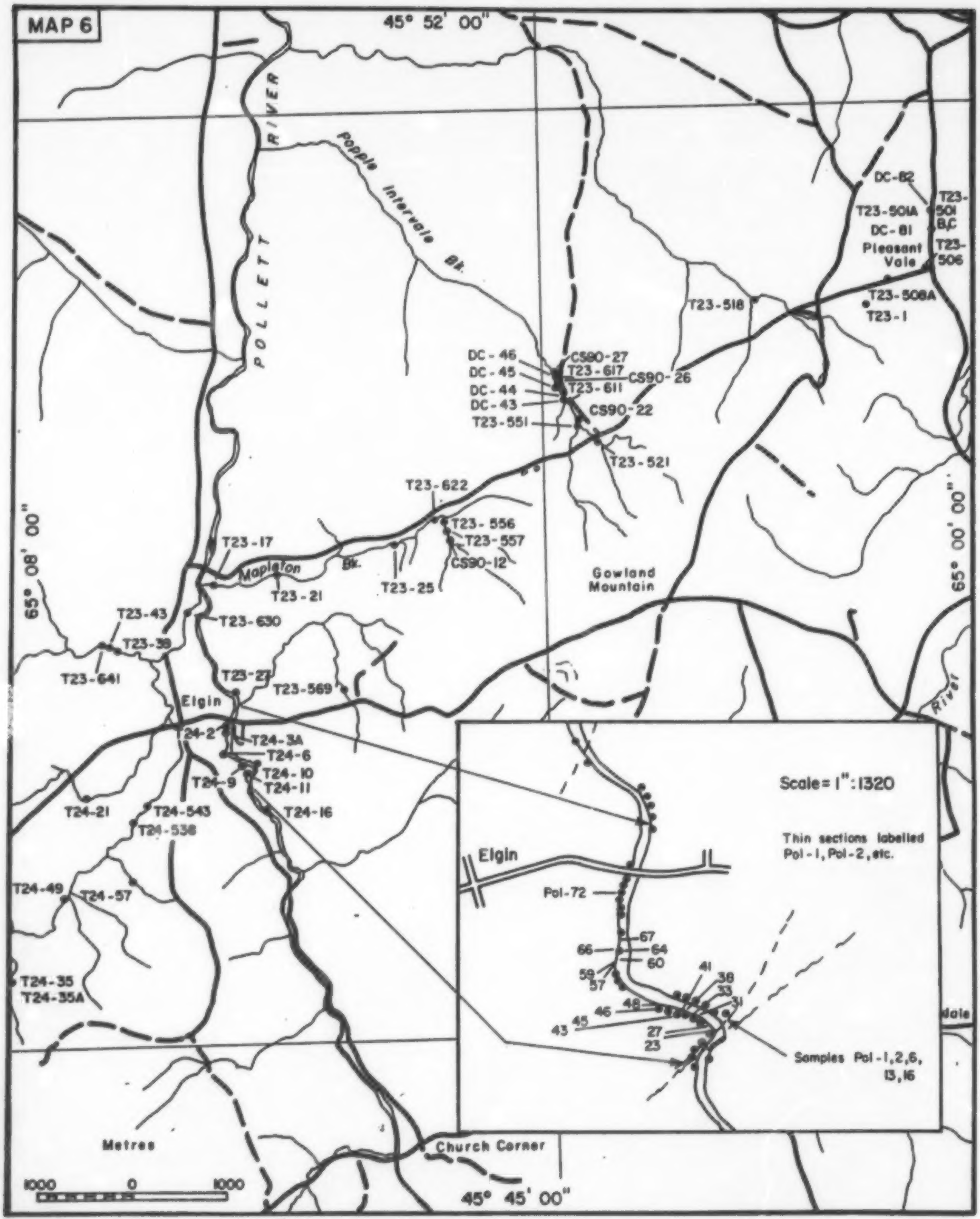
Dorchester

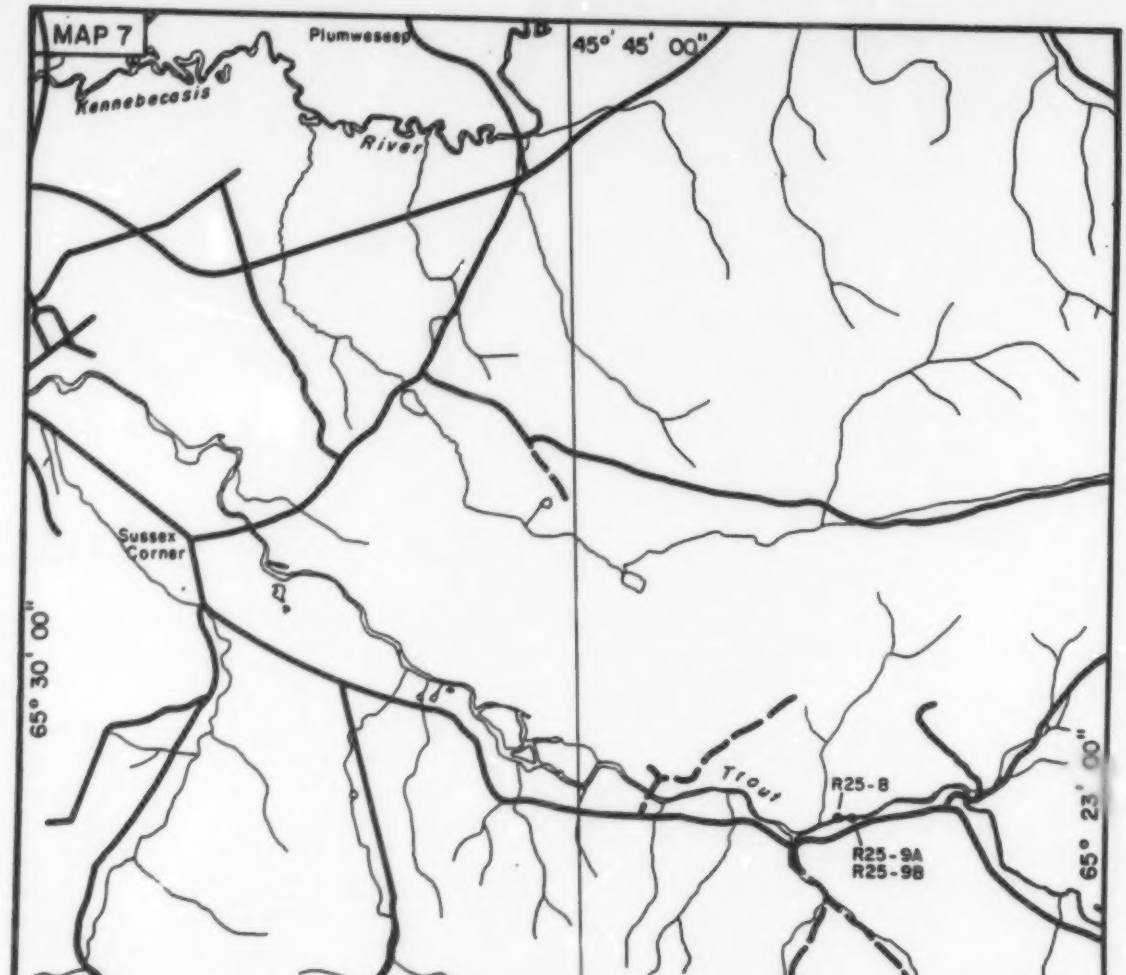

MAP 3

46° 00' 00"
Stoney Creek
V22-87
V22-88
V22-89
V22-90
Downing
Ck.
V22-31
V22-4A
V22-4B
DC-78,DC-78B
DC-79A, DC-79B
DC-80
STONEY CREEK
GAS & OIL
FIELD
P8
V22-67
V22-61
V22-59
V22-111
V22-109
V22-108A
V22-107B
V22-106
V22-105A,C,D,F,H
V22-104
V22-102
V22-101
V22-103
V22-100A
V22-100B
Scale
" =1/4 mile
V22-547
V22-106
V22-98a
Gautreau
Village
V22-92
P
PETITCODIAC
Weldon
Sifto W3
65° 45' 00"
64° 38' 00"
HILLSBOROUGH
Salem
Frederick Brook
Edgett's
Landing
V23-139
V23-116
V23-619
V23-143
V23-149
V23-588
V23-594
CS90-16
CS90-19
V23-4
V23-12
V23-206
V23-61
V23-608
V23-84-13A,C
V23-84-10
V23-84-8
V23-84-5
DC-20
V23-91
V23-93
V23-51
V23-50
V23-49
V23-85
V23-81
V23-80
V23-44
V23-38
V23-15
V23-16
V23-26
DC-24
DC-8
DC-7
DC-23
V23-541
Albert Mines
Metres
1000
0
1000
45° 52' 00"


MAP 4
45° 55' 00"
Upper Turtle Creek
Creek
Beach Hill
Turtle
V23-526
64° 53' 00"
Creek
64° 45' 00"
U23-528
U23-524
U23-522A
U23-507
RV-5
RV-3
U23-20
Rosevale
U23-519
U23-512
U23-517
DC-52
U23-547
U23-533
U23-536
Stuart Bk.
U23-15
U23-56
U23-17
U23-15a
U23-589
U23-78
U23-2
U23-4
Metres
1000
0
1000
45° 48' 00"


MAP 5
45° 55' 00"
Little River
65° 00' 00"
River
Parkindale
64° 53' 00"
U23-113
U23-621
U23-621C
U23-628
U23-628A
U23-631B
U23-636
Prosser Brook
U23-594
U23-572A
Little River
Metres
1000
0
1000
45° 47' 00"


MAP 6
45° 52' 00"
45° 45' 00"
65° 08' 00"
65° 00' 00"
POLLETT RIVER
Popple Intervale Bk.
Mapleton Bk.
River
Gowland Mountain
Pleasant Vale
Elgin
Church Corner
dale
DC-82
T23-501A
T23-501 B,C
DC-81
T23-506
T23-508A
T23-1
T23-518
DC-46
DC-45
DC-44
DC-43
CS90-27
T23-617
CS90-26
T23-611
CS90-22
T23-551
T23-521
T23-622
T23-556
T23-557
CS90-12
T23-17
T23-21
T23-25
T23-43
T23-630
T23-38
T23-641
T23-27
T23-569
T24-2
T24-3A
T24-6
T24-10
T24-11
T24-9
T24-16
T24-21
T24-543
T24-538
T24-49
T24-57
T24-35
T24-35A
Metres
1000 0 1000
Scale= 1":1320
Thin sections labelled Pol-1, Pol-2, etc.
Elgin
Pol-72
67
66
64
60
59
57
41
38
33
31
48
46
45
43
27
23
Samples Pol-1,2,6, 13,16


MAP 7
Plumweseep
Kennebecasis
River
45° 45' 00"
Sussex Corner
65° 30' 00"
Trout
R25-8
R25-9A
R25-9B
65° 23' 00"
S25-84-139
S25-84-141
S25-84-45
S25-84-215
S25-84-46
R25-14
R25-24B
R25-25
S25-84-203
S25-4
S25-84-14
S25-5A
Metres
1000 0 1000
45° 38' 00"

MAPS
NOT
FILMED

CARTES
OMISES